

# A Review of Holograms and other Microstructures as Security Features<sup>1</sup>

Rudolf L. van Renesse<sup>2</sup>

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## Abstract

After the invention of rainbow holography by Stephen Benton in 1969 and the development of hologram micro-embossing, mass replication of hologram became possible. Soon the potency of holograms as security features for valuable documents and products was realised and 1980 saw the first commercial application of embossed rainbow holograms. Since the application of the hologram as a security feature has assumed large proportions. This development of security features has not halted at the application of holograms. A great variety of other diffractive microstructures has been developed, commonly referred to as *diffractive optically variable image devices* (DOVIDs). Currently DOVIDs are manufactured not only by holographic and laser interference techniques but also by advanced electron beam lithography. Apart from diffractive security structures, a variety of microstructures based on thin film interference have been developed, Denisyuks volume reflection hologram leading the way. Currently many of these interference structures are based on advanced vacuum deposition technologies, these being referred to as *interference security image structures* (ISIS). This article discusses and illustrates the various types of DOVIDs and ISISs that find an application in document and product security or are proposed as such.

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<sup>2</sup> Formerly with TNO Institute of Applied Physics, Delft, the Netherlands; since 2002 VanRenesse Consulting, The Hague, The Netherlands.

Email: <mailto:rvr@vanrenesse-consulting.com>, website: [www.vanrenesse-consulting.com](http://www.vanrenesse-consulting.com).

## 1 Introduction

Holograms, in the sense of the term that Dennis Gabor coined in 1947, are media that, on illumination with a first wave front, generate a second wave front that constitutes an optical reconstruction of a three dimensional space [1,2]. After the invention of the laser, Leith and Upatnieks invented off-axis holography [3], while Denisjuk invented volume reflection holography [4]. These inventions allowed an astounding demonstration of the full 3-D display capability of the hologram. It is this 3-D display that has fascinated many. And it is also this 3-D aspect that makes the medium actually a hologram.

Once Benton invented rainbow holography [5], white light reconstruction of off-axis holograms became possible at the expense of vertical parallax. The subsequent development of the micro-embossing technique allowed mass replication of the rainbow hologram.

It was soon realised that rainbow holograms might be used as security features on valuable documents and products, and in 1980 the first commercial use of embossed rainbow holograms by United States Banknote Company (USBC) was a fact [6]. Thus, classical hologram became the first of a manifold of diffractive structures developed to thwart counterfeiting. Many of these diffractive structures can no longer be called holograms in the strict sense, because they only display 2-D images. Also some of these diffractive structures are no longer made by laser interference techniques, but are created by advanced electron beam lithographic techniques.

Denisjuk's volume reflection hologram, based on light interference, has also been supplemented by non-holographic thin film interference structures, produced by advanced vacuum deposition techniques [7,8].

All of these security features are characterised by an iridescent display of colours with angle of observation, and such security features became generally referred to as *optically variable devices*, or *OVDs*. Nowadays, the diffractive type security feature is frequently referred to as *diffractive optically variable image device (DOVID)*, while the interference type security feature is conveniently referred to as interference security image structure (*ISIS*). For the non-expert it is difficult, if not next to impossible, to distinguish between all these types of iridescent features, and a tendency developed to refer to many types of OVD as "hologram". Figure 1 gives a schematic overview of the various types of OVD that are now used, or at least proposed, in the document and product security industry. The reader will understand that it is impossible to mention all these features in detail in this review; a series of examples together with comprehensive references must suffice.

OVDs have a few important properties in common, that make them unique as security features.

1. Photographs, colour copiers and modern desk top publishing (DTP) systems are unable to reproduce their iridescent effects. OVDs thus offer adequate protection against photomechanical copying systems.
2. The production of OVDs tends to be complex and requires special, expensive equipment and specialised professional know how. As a consequence, OVDs tend to offer good protection against remaking.
3. The iridescent effects of OVDs tend to be conspicuous and easily observable in first line inspection. (First line inspection takes place using the sense-organs only, without the aid of tools.)

## 2 Diffractive Optically Variable Image Devices (DOVIDs)

When looking at a point source through a birds feather or a silk screen, various diffraction orders are observed: the zero order, undiffracted light, the first order diffracted light and higher diffraction orders. In document security the zero and first order diffraction of various grating structures are of interest.

Practically all DOVIDs are of the first order diffraction type. Apart from *first order devices* also called *first order DOVIDs (FODs)*, *zero order devices* exist, also called *zero order DOVIDs (ZODs)*. ZODs are composed of gratings with a line period that is even smaller than the wavelength of light. The optical properties of ZODs differ strongly from those of FODs.

DOVIDs are produced by exposing a photo lacquer (photo resist) and subsequently creating embossing masters from the exposed and developed micro-relief by electro-plating [9,10]. Figure 2 shows the schematic cross sectional composition of DOVIDs. The method used to expose the photo lacquer is of immediate interest for the security value of the DOVIDs. Two principal methods are distinguished: traditional light interference techniques and advanced lithographic techniques.

### Traditional light interference techniques

By far and away most DOVIDs are produced by the traditional method of light interference. The photo-resist is exposed by two laser beams, incident at different angles, to create a line pattern. It is important to note that light interference techniques result in a photo resist relief pattern that has a symmetrical, sinusoidal cross section. Sinusoidal gratings diffract an equal amount of light into both first orders. As a result, DOVIDs made by light interference look basically the same in both the plus and minus first order.

**Counterfeiting** - The know how to put this traditional method of grating production to use, is currently spread world wide. This implies the threat of *counterfeiting* (remaking). As a result, a tendency exists to create very complicated image structures that, hopefully, will be difficult to counterfeit. The inherent disadvantage of such complex images, however, is the difficulty humans have to adequately inspect them.

**Optical replication** - Furthermore, gratings made by light interference can be easily replicated in photo resist. This can be accomplished by so called *optical replication*: either by one step *laser copying* or by two step *holographic copying*. From this optical replica in photo resist, embossing dies can be made again and, subsequently, mass production of exact copies is a relatively simple matter for the many skilled in the art [11].

**Mechanical replication** - Figure 2 shows the embossed relief embedded between two protective polymer layers. In absence of a protective layer it is simple to uncover the surface relief by dissolving the adhesive layer. Then, *mechanical replication* of the surface relief is possible by electro-plating an embossing die on the relief, after which nothing stands in the way of illicit mass replication of the original DOVID [11]. A good security feature is so constructed that attempts to lay bare its surface relief, lead to its destruction.

### Advanced lithographic techniques

With the aid of advanced lithographic techniques, such as electron beam lithography, gratings can be exposed, line by line, into appropriate photo lacquers. This technology also allows to create blazed gratings with an asymmetrical cross-section, that diffract significantly more light into the plus first order than into the minus first order [12-16]. As a result, DOVIDs with blazed gratings show striking differences in contrast between the plus first and minus first order diffraction. A simple rotation over 180° suffices to display the effect. Optical copies no longer display this contrast swap (section 2.1.6 Vector oriented).

Another possibility is the manufacture of volume type gratings such as created in the ZOD. Chemical etching methods or ion beam etching are used to create such volume structures. They also display unique and obvious optical effects (section 2.2 Zero order DOVIDs).

These advanced grating structures can be neither produced by traditional laser interference methods nor can they be replicated by optical means. Consequently, the unique optical effects they display offer significantly increased resistance against all types of remaking and replication.

These lithographic techniques involved are considerably more complicated than classic interference techniques, and the required equipment is much more expensive than traditional equipment. Also the know how required for these lithographic technologies is not wide spread. Yet, mass production has appeared possible within acceptable price limits.

## **2.1 First order DOVIDs**

Virtually all FODs have one property in common: they function optimally under illumination by a point source, while under complete diffuse illumination an infinite number of images merges and all iridescent effects disappear. Also 3-D information becomes gradually lost with increasing diffuseness of the illumination. The deeper the image plane is below the surface of the hologram, the more unsharp it becomes under diffuse illumination. Because the inspection of security features takes place under a variety of lighting conditions, this obviously is a disadvantage of FODs. Blazed diffraction structures, incorporated in some kinegrams, are an exception; their optical effects can be well observed under diffuse illumination.

The lively iridescent colours displayed by FODs are indisputably attractive, but from a viewpoint of security inspection they have no particular significance, because such colour changes can be hardly if at all defined. It is the image content of these features that carries the relevant information for inspection. Contrary, zero order devices display colour shifts that can be properly defined (section 2.2 Zero order DOVIDs). The simplest FOD is of the single channel type; it displays only one image. An example is the Visa card rainbow hologram of a dove. An example of a multi-channel FOD is the MasterCard dual-world globe logo, displaying different images with different angles of observation. Further complexity can be introduced by kinematic image effects (section 2.1.6 Vector oriented) and holographic stereogram animations (section 2.1.7 Time domain oriented).

### **2.1.1 Spatial domain oriented**

**Hologram (3-D)** - A hologram displays a 3-D image in space and is simply referred to as 3-D. Holograms that are applied as security features are almost without exception rainbow holograms. An example of a purely holographic security feature is the Visa card hologram. Purely single channel holographic security features are becoming rare because, currently, they can be counterfeited relatively easy in a well equipped holographic laboratory.

**Multiplane hologram or 2-D/3-D** - Often a hologram (3-D) simply consists of two or more two-dimensional image planes located at different depths. For instance, a 2-D image plane flush with the surface of the hologram and another 2-D image plane a few millimetres underneath. This is a relatively inexpensive type of hologram, simply referred to as *2-D/3-D* or *multiplane* hologram. In diffuse illumination the image plane on the surface remains sharp, but the image plane, a few millimetres underneath becomes unsharp. This effect is illustrated in Figure 3.

**2-D type features** - The simplest first order structures consist of a collage of relatively large diffractive elements, each with a particular line frequency and azimuth. Such a collage forms an image that, while being tilted, appears in all kinds of iridescent colours. The iridescent image is “flat”, without any 3-D effect. Such images are referred to as *2-D* features. Often they are composed of repetitive wallpaper type patterns. Application is generally limited to utility articles (food, drinks, etc.). They tend to serve as promotional features rather than as security features.

DOVIDs with a relatively high security value can also be of the 2-D type. However, they present images with fine graphical details, microtext, kinematic effects, movie type animations and sometimes unique optical effects. These 2-D DOVIDs will be discussed in the sections 2.1.2 Graphical element oriented to 2.1.6 Vector oriented and 2.2.1 Diffractive Identification Device (DID).

### 2.1.2 Graphical element oriented

Many DOVIDs are composed of various separate graphical elements such as logo's, geometrical planes, guilloches, microtext, etc. Each of these graphical elements is a diffractive element as such, or it is composed of a number of combined diffractive elements that, together, display a kinematic effect. The various graphical elements are projected in high-precision register on the photo lacquer from separate masks. An example of a graphical element oriented feature is found on the 20 Mark Finnish banknote (see Figure 4).

### 2.1.3 Dot oriented

The *dot matrix* feature is created dot-by-dot with the use of two interfering laser beams which focuses coincide on the photo lacquer which is mounted on a high-precision step-and-repeat carrier. By varying the angle of incidence of the laser beams, period and azimuth of the interference fringes in the focal point are adjusted. Each focal dot thus is a grating with a single frequency and azimuth. An example of a dot-matrix feature is given in Figure 5. Dot-matrix images can be composed in great detail with extremely fine dots (see Figure 6).

The dot matrix technique is an extremely versatile technique that allows the computer generation of any traditional 2-D DOVID image by the suitable composition of innumerable microscopic dots. This technique, therefore, is extremely suited for the making of deceitful imitations of any 2-D type security feature. The dot matrix engine, therefore, may become a threat to the security of 2-D DOVIDs, comparable to that of the colour copier to traditionally printed artwork.

### 2.1.4 Pixel oriented

The *pixelgram* (CSIRO, Australia) is made by the use of E-beam lithography and consists of a regular matrix of fine rectangular pixels as diffractive elements (see Figure 7). The pixel's fringe pattern is not uniform, but consists of lines that continuously vary in frequency and azimuth. This is schematically shown in Figure 8.

The first diffraction order of pixels with a fringe pattern that considerably varies in frequency and azimuth (Figure 8a) fans out into a broad beam. Such pixels will light up at many angles of illumination and observation, and thus are generally seen as “light pixels”. In contrast, the first diffraction order of pixels that contain lines with an only small variation in frequency and azimuth (Figure 8b), diffract light into a narrow, pin-pointed beam. Such pixels will generally be seen as “dark pixels”, but once observed exactly so that this narrow beam enters the pupils of our eyes, they will light up with extreme brightness. By producing pixels with all intermediate fringe characteristics, a continuous brightness scale is created which allows the making of continuous tone portraits. If the pixelgram is observed so that the “dark pixels” light up, these will be experienced as the brightest. As a result the image reverses contrast (Figure 9). The pixelgram never found its way to the security market and is now superseded by the *exelgram* (section 2.1.5 Track oriented).

### 2.1.5 Track oriented

The successor of the pixelgram is the *exelgram* (CSIRO, Australia). The root ‘exel’ is derived of ‘exposure element’ indicating that these diffractive elements can be exposed with the fundamental resolution accessible by E-beam lithography. The *exelgram* is a *track oriented* 2D security feature. Like a television screen is composed of adjacent, parallel lines that locally vary in brightness, the *exelgram* is composed of diffractive tracks, with

fringes that locally vary in frequency and azimuth. This is schematically illustrated in Figure 10. The diffractive tracks have a width of a few tens of microns and can assume any arbitrary length within the size of the exelgram. Exelgrams have appeared on various valuable documents; its best known application is that on the American Express travellers cheque.

### 2.1.6 Vector oriented

The *kinegram* (OVD Kinegram Corporation; formerly Landis & Gyr Communications Corp.) is a vector oriented security feature. Unlike the adjacent, parallel tracks that compose the exelgram, the kinegram is composed of diffractive lines oriented in different directions. The kinegram is the original security feature that displays kinematic effects such as translation, rotation, expansion, contraction and complete transformations from one graphical element into another. Currently, kinematic effects are displayed by many DOVIDs. Kinematic effects are brought about by the combined diffractive responses of related graphical elements, each with a slightly different line frequency and azimuth. The light diffracted by each separate graphical element is observed in one single angular orientation of the feature. By rotating or tilting the kinegram, each phase of the animation is observed in turn, so that an apparent movement takes place. Figure 11 illustrates the principle of kinematic effects.

Kinegrams are manufactured with advanced lithographic techniques, that allow the generation of blazed gratings. Figure 12 schematically illustrates this effect of the application of blazed gratings. Figure 13 shows the blaze effect displayed by the kinegram of the Dutch Postbank "Giropas".

### 2.1.7 Time domain oriented

A special type of rainbow hologram is the so called *holographic stereogram*. On being tilted, the stereogram displays a brief 3-D cinematographic animation. This 3-D movie fragment is recorded in the hologram as a composition of a number (sometimes less than ten, sometimes more than one hundred) movie frames. During recording the movie fragment the scene may be rotated on a revolving platform, or otherwise the camera may slide along the scene. The holographic stereogram is composed of adjacent, narrow vertical slit-shaped holograms of subsequent movie frames. Each eye observes the image through different slits and, consequently, sees an image of the moving object with a different angular rotation. This angular difference creates a three-dimensional impression, identical to that of the classic photographic stereogram. The manufacture of holographic stereograms requires an elaborate laboratory set-up, which warrants a considerable threshold against counterfeiting. Figure 14 shows an example of a holographic stereogram on the Eurocard (American Bank Note Holographics, USA). On tilting, while being illuminated by a point source, the feature shows an impersonation of Beethoven saluting and winking the eyes.

## 2.2 Zero order DOVIDs

Zero order devices (ZODs) form a separate branch of DOVIDs at the OVD tree (Figure 1). Contrary to FODs, ZODs are inspected about the zero order in specular reflection. They display conspicuous colour effects that are very sensitive to the in plane rotation of the device.

ZODs are composed of gratings with periods ( $p$ ) smaller than the wavelength of light ( $p \leq 400$  nm). The line frequency is beyond 2500 1/mm, so that the first order diffraction is at a too large angle to be existent. The optical behaviour of ZODs is also defined by the particular three-dimensional cross section of the diffractive grating. Currently, commercial application of ZODs to document security is not realised, but in the course of 1999 Hologram Industries (France) is expected to put these on the market.

In nature such rotation sensitive sub-micron structures are found on the wings of butterflies such as the Morpho rhetenor and the purple emperor (*Apatura iris*) and on the sheet wings of some beetles.

### 2.2.1 Diffractive Identification Device (DID)

The basic structure of security ZODs consists of a high index dielectric lamellar grating of rectangular cross section, embedded in a low index polymer matrix (Figure 15). These security structures are developed by the Paul Scherrer Institute (Switzerland) and have been coined *diffraction identification device* (DID) [9]. The DID is not yet commercially available, but in the course of 1999 Hologram Industries (France) is expected to put these on the market.

The optical behaviour of the DID is unique and very different from that of either first order structures (section 2.1 First order DOVIDs) or ISISs (section 3 Interference Security Image Structures (ISISs)). The DID efficiently reflects narrow wavebands. For example, a red to green colour shift is observed, while rotating the DID in its own plane over 90° (Figure 16). Otherwise the DID is highly transparent, making it exceptionally suitable as a security overlay (Figure 17). The light reflected by the DID is highly linearly polarised. The iridescent effects of

the DID are well defined and are visible under diffuse as well as point source illumination. Both these properties give the DID an advantage over first order devices.

Because the fringe structure is embedded in a polymer matrix, mechanical replication of DIDs is not feasible. Neither is optical replication possible by contact copying or holographic techniques, because these do not allow the reproduction of the specific three-dimensional volume fringe structure.

The mass production of DIDs entails high resolution laser interference lithography, dry etching techniques, electroplating to manufacture the embossing die, continuous embossing of polymer film, deposition of the high index material and overcoating of the embossed relief with a transparent polymer film.

### 3 Interference Security Image Structures (ISISs)

DOVIDs and ISISs are each others counterparts. The DOVID is composed of adjacent fringes, while the ISIS consists of one or more thin films. The volume reflection hologram is an example of the latter. Although many other types of ISIS are not related to holography, they are mentioned in the following for the sake of completeness, but are not discussed in detail.

#### 3.1 Single layer structures

Single layer, low index thin films display a strong colour shift with angle of observation, but have a low reflectivity. Thin soap films and oil films are examples. Contrary, single layer high index thin films efficiently reflect light, but display a negligible colour shift. High refractive index, single layer structures, are sometimes applied to valuable documents as a security feature, because of their brilliant reflection. Pearl lustre pigments are the only example.

##### 3.1.1 Pearl lustre ink

The only example of a single layer ISIS is so called pearl lustre ink, consisting of microscopic transparent mica flakes added to a transparent printing ink. The mica flakes carry an interference layer of high index  $\text{TiO}_2$  ( $n \cong 2.7$ ), reflecting approximately 30% of the light in a visible waveband. The reflected colour depends on the thickness of the interference layer. During printing the micro flakes orient parallel to the substrate, resulting in a uniform gloss of interference colours. Pearl lustre ink is found on, amongst others, on Swiss banknotes. Outside the glossy reflection the ink is transparent and only the substrate colour is visible. Because of the high refractive index of  $\text{TiO}_2$ , disadvantageously, no appreciable colour change with angle of observation exists. Iridescent pigments are cheap and widely commercially available.

#### 3.2 Multilayer structures

In general the commercial availability of multilayer ISISs is restricted to use on high security products and documents. Two types are distinguished refractive-type multilayers and Bragg-type multilayers (Figure 1). An example of a multi-layer structure in nature is the peacock feather that consists of alternate layers of melanine and keranine.

*Refractive-type multilayers* - These consists of a limited number of deposited layers (mostly 3 to 5, occasionally up to 9) with large differences in refractive index to render the stack a high reflection. Optically variable ink (OVI) is an example. If the average refractive index of the coated stack is sufficiently low, the refractive-type ISIS combines a considerable reflection with a strong iridescent colour shift.

Two types of refractive multilayers are distinguished.

1. The *all-dielectric* stack consists of transparent substances such as  $\text{Al}_2\text{O}_3$  ( $n=1.76$ ),  $\text{ZrO}_2$  ( $n=2.2$ ),  $\text{SiO}_2$  ( $n=1.54$ ),  $\text{TiO}_2$  ( $n=2.7$ ),  $\text{ZnS}$  ( $n=2.6$ ),  $\text{MgF}_2$  ( $n=1.38$ ), etc. These combinations are semi-transparent and are applied as security overlays over variable information (Figure 18). An example is found on the British Columbia driving licence.
2. The *metal-dielectric* stack is opaque and combines dielectric and metals layers (e.g. Al, Cr). Examples are found on Canadian banknotes and in optically variable ink (**Figure 19**). On the new US dollar currency design the denomination is printed in a green to black shifting OVI.

It has appeared relatively simple to establish the composition of such thin film stacks in a well equipped laboratory. Their security value therefore is not based on the secrecy of the composition, but only on the complexity of their manufacture and the considerable know-how required. Security based on secrecy is generally considered inferior.

*Bragg-type multilayers* - These consist of many tens to hundreds of layers that slightly alternate in refractive index, together rendering a high iridescent reflection. Three types of volume reflection structures are distinguished.

1. Volume reflection holograms generally serve holographic art and promotional applications (book covers, packaging, buttons, etc.). DuPont has developed photo-polymer holographic materials that allow mass production of reflection holograms, now also promoted for security applications .
2. Co-extruded thermoplastic layers. The foils obtained in this manner are widely used in the packaging industry and shop-window designs. A security application is the addition of small planchets to security paper during paper manufacture.
3. Photo-polymerised liquid crystals.

### 3.2.1 Volume reflection holograms

Volume reflection holograms display large colour shifts, because of the low refractive index of the medium. The colour under normal observation depends on the recording wavelength of the laser light and the waveband shift caused by the eventual thickness change of the recording medium due to processing. Volume reflection holograms can be used as semi-transparent overlays, but are mostly provided with a black backing to block light scatter by the substrate. Volume reflection holograms are mainly found in galleries. They are also applied as promotional features on books, packages, luxurious goods, etc. and are sometimes used as security features.

An efficient mass-production technology such as embossing does not exist for volume reflection holograms. Each copy of a volume hologram must be newly made from a master hologram by laser recording and subsequent processing. Volume holograms were originally recorded in high resolution photographic media like silver halide film or dichromated gelatine. Because these recording media required complex photochemical processes, mass production was time-consuming and expensive. DuPont (USA) and Polaroid (USA) have developed holographic photopolymers. The DuPont photopolymer processing after exposure simply consists of a heat treatment; this process can be automated and now allows some form mass production.

Because each copy must be individually exposed, each hologram can be individually provided with variable information. Hologram numbering can, for instance, be achieved by recording a liquid crystal display in one of the channels. Otherwise, by applying a computer-controlled raster-scanning laser beam as an object beam, each hologram can be made unique by dot writing additional holographic serial numbers, bar codes, signatures or even photographs in the photosensitive layer.

Even multi-channel type volume holograms are relatively simple to originate and the necessary know-how and skill exist on a world-wide scale. Also, their holographic replication is possible by holographic techniques.

#### *Flashprint*

Volume reflection overlays in silver halide film were originally proposed for promotional and security applications by Ilford (UK), under the trade name *Flashprint* [17]. Flashprint displayed extremely bright 2-D image elements, visible only in a narrow angular viewing area, and no 3-D objects. Unsharpness of the holographic reconstruction due to extended light sources, therefore, did not occur.

Ilford never made a market for Flashprint and the application of volume reflection holography to document and product security remained insignificant. The rights for the Flashprint technology were obtained by the British Technology Group (BTG) [18]. Currently, the DuPont holographic photopolymer allows the mass production of volume reflection holograms in a considerably more cost effective manner. BTG promotes the application of DuPont's photopolymer to Flashprint.

#### *Polaroid's Mirage*

Polaroid (USA) developed a high quality photopolymer called DMP-128. The photosensitive material was not for sale, only ready-made holographic images were supplied under the tradename *Mirage* [19]. In a few cases these volume holograms were applied as security labels with a tamper proof backing. In 1998 Polaroid abandoned display holography [20].

#### *Krystalmark*

Krystal Holographics (USA) has moved into the area of document and product security with volume reflection holograms, recorded on DuPont's photopolymer, under the tradename *Krystalmark* [21]. An example of a multi-channel volume reflection photopolymer hologram is presented in Figure 20. Krystal Holographics claims production capabilities of millions of holograms per week. Although this does not compare with production capabilities of embossed holograms on rotation machines, this seems an impressive achievement.

### 3.2.2 Iridescent planchets

Volume structures are produced by coextrusion of thin thermoplastic films, for example consisting of alternating low index layers of polypropylene ( $n=1.49$ ) and poly-carbonate ( $n=1.59$ ). The low refractive index makes these foils, that are mainly used in the packaging industry and as embellishment, strongly iridescent. However, the iridescent colour distribution over the foil surface is non-uniform. Because of the wide availability and the low price these foils as such do not have a large security value.

During the production of security paper, iridescent planchets of a few millimetres diameter are sometimes added to the pulp, where they are held at the surface by the paper fibres. The back of the new design Dutch 10, 100 and 1000 guilder banknotes is provided with such iridescent planchets (Figure 21).

### 3.2.3 Photo-polymerisation of liquid crystals

Polymerisation of liquid crystals forms a third method to manufacture volume structures. The molecular structure of *cholesteric liquid crystals* is such that layers are created with a periodicity of one half wavelength. Cholesteric liquid crystals are pressure sensitive and thermochromic and tend to be chemically unstable. By photo-polymerisation once the liquid crystals have been rendered the right temperature and pressure, they can be stabilised in the desired state and form a thin, fragile iridescent layer. This technology has found a successful application in the Advantage seal (Advantage Technology Inc., USA), a transparent feature that displays a red to green colour shift (Figure 22). Because of the chiral molecular construction, the light reflected by these photo-polymers is highly circularly polarised.

## 4 Machine reading of OVDs

Apart from human inspection of OVDs for authenticity, machine inspection of OVDs is an option. OVDs possess a variety of machine readable properties, such as polarisation, phase structures, spectral response, the angular distribution of diffraction orders, and the ratio of diffraction efficiency for different diffraction orders.

Souparis discusses various methods of machine detection of diffraction orders of DOVIDs [22]. Machine detection of asymmetric diffraction by blazed gratings is discussed by Tompkin e.a [23,24]. Machine readable holograms that withstand remaking as well as holographic replication are discussed by Dausmann [25].

The machine detection of the polarisation of light is proposed for DIDs [9] as well as for polymerised liquid crystal devices [26]. Also, the automated detection of the spectral response and angular diffraction of DIDs are proposed [9].

Machine authentication of the angular spectral response seems the only option for ISISs.

Two types of machine authentication are distinguished. Machine authentication can be fully automated to give a simple accept/reject decision [22-25] or the authentication may require human interpretation of an image, displayed by the reading equipment. Properties that serve human inspection of DOVIDs with the aid of machine reading are covert images [27-30].

## 5 Discussion

The rise and steady perfection of colour copiers and DTP systems since the late seventies was the incentive for the development of a totally new security feature, a feature that could not be copied with these document copying systems and that allowed easy visual inspection. Soon after rainbow holography [5] and mass replication embossing techniques were invented, the classical hologram took the leading role in this development. The first security hologram appeared in 1980 [6]. It was in 1990 that McGrew [11] pointed out the weaknesses of the classical hologram and suggested various solutions to overcome these weaknesses. In the past few decades numerous iridescent structures have been developed and commercially applied as security features to valuable documents and products [7,31]. Holograms, and DOVIDs in general, have since advanced and still play the major role in the area of product and document security. The variety of currently existing security structures is illustrated in figure 1.

No particular security feature, whether a DOVID or an ISIS, is a panacea against all fraudulent activities. However, DOVIDs and ISISs may have a supplementary function. It may be advantageous to ergonomically combine both types of OVD into one single device with optical effects that provides optimum first line inspection as well as optimum security against counterfeiting.

Machine detection of iridescent OVDs has been advocated and offered frequently, and for a good reason, because these features can provide an extremely secure second line defence against counterfeiting and forgery. However, no major commercial breakthrough has yet taken place in this regard, the main complication probably being the required large scale distribution and integration of dedicated reading equipment.



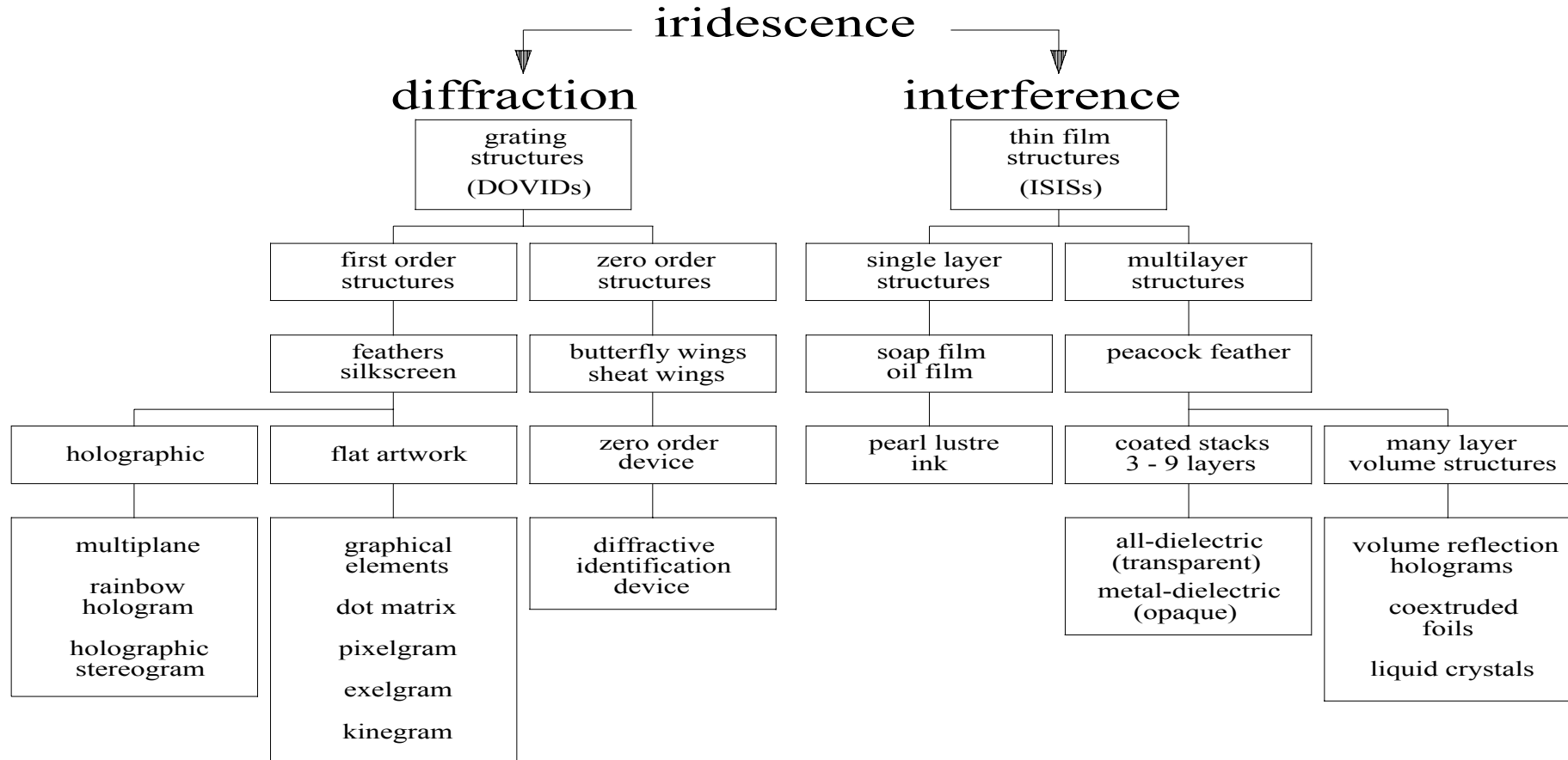
Hence, first line inspection of OVDs plays the leading role in the field of document and product security. Obviously, the security level will depend largely on the ergonomics of the security design as well as on the attentiveness of the acceptor and his knowledge of what to look for.

In the last few years, this ergonomic requirement has been frustrated by the fact that counterfeit goods have been issued in increasing quantities by criminal organisations [32]. DOVIDS also are the subject of these organised malversations. As a countermeasure, manufacturers of DOVIDs have shown a tendency to increase the image complexity of their products to such an extent that their faithful origination has become difficult. Unfortunately, such complex images do neither allow adequate inspection by the non-expert. Thus, a disadvantageous trade off between ease of inspection and confidence in the authenticity of the product results. Evidently, this pursued image complexity is not in the interest of the efficacy of first line inspection. It is therefore required to apply simple and ergonomic image designs, based on complex nano-structures that are difficult to counterfeit and at the same time display simple images that allow ergonomic inspection. In this manner, in stead of a disadvantageous trade off, a combination of easy inspection in first line and confidence in the authenticity of the security feature are achieved [33]. The above mentioned combination of DOVIDs and ISISs may also be an approach to achieve this result.

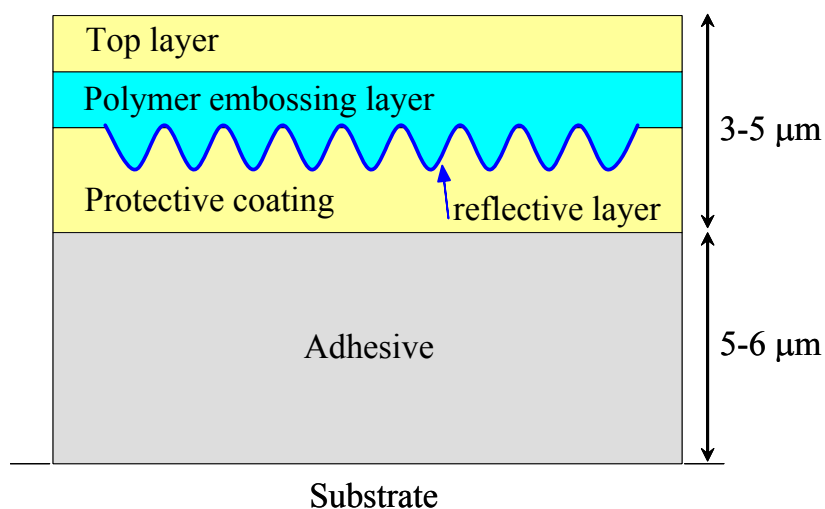
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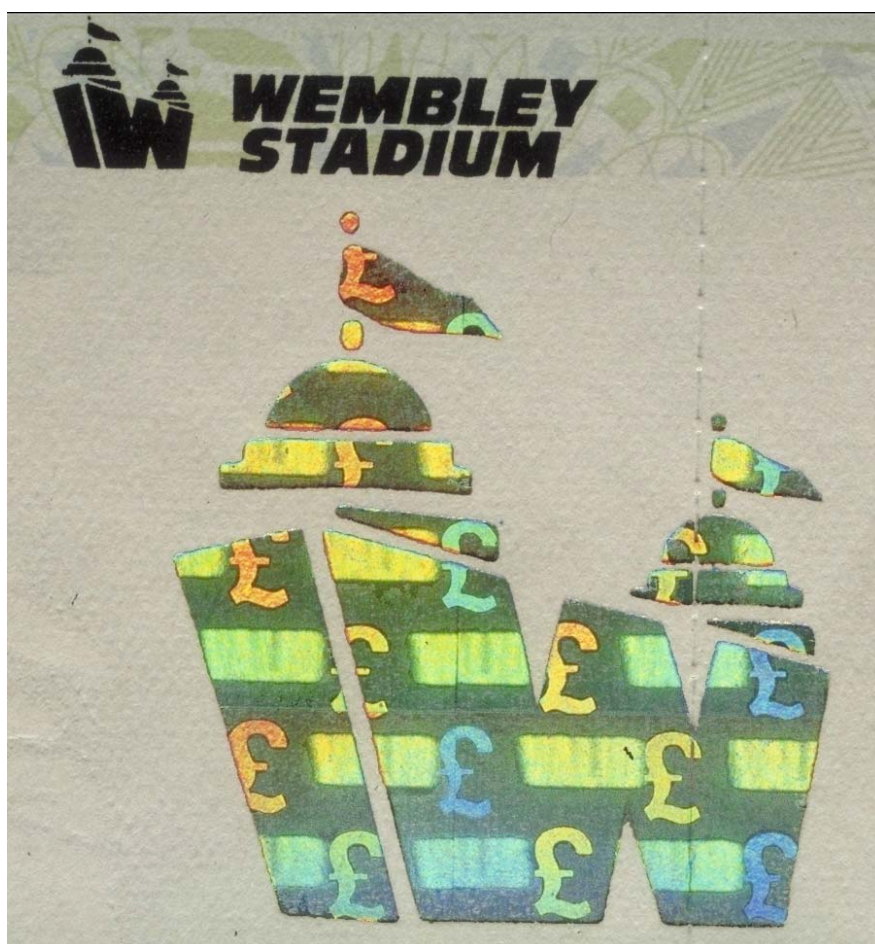
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**Figure 1** - The tree of iridescent OVDs: iridescence in nature and as applied to document security.



**Figure 2** - Schematic cross section of the basic composition of an embossed grating. The thickness of the various layers is not to scale and measures only about 10 μm.



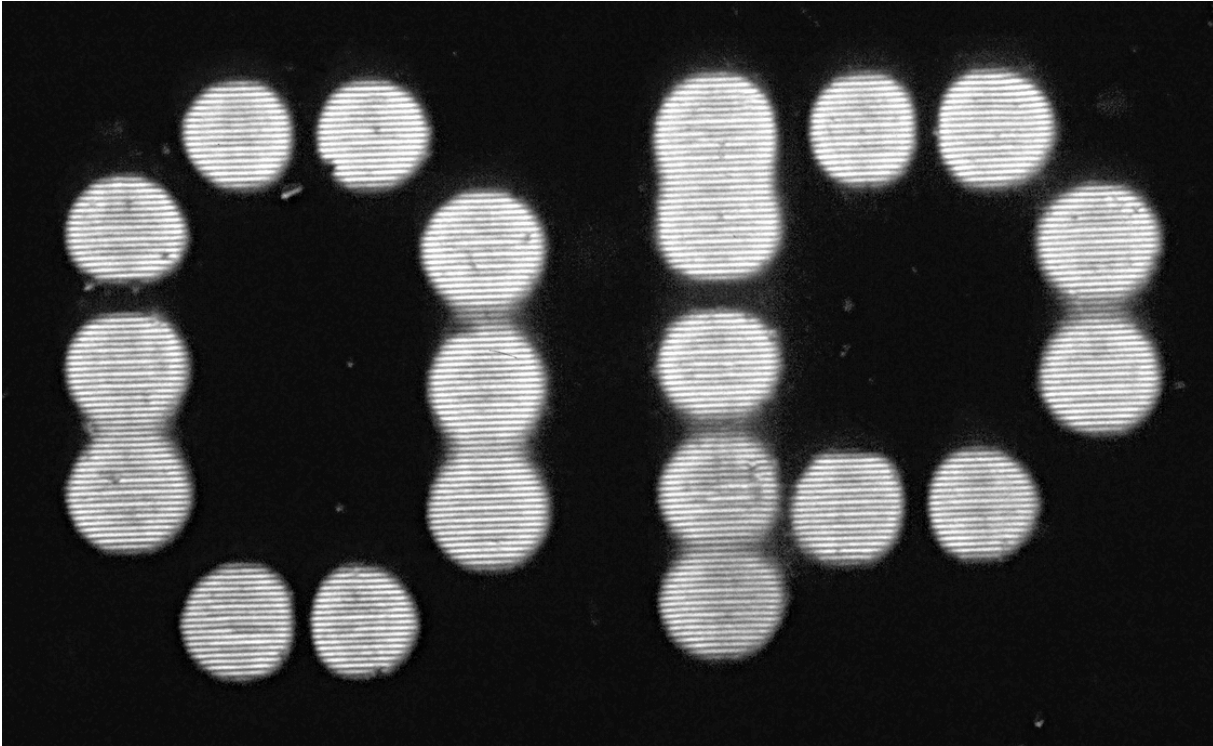
**Figure 3** - A 2D/3D (multiplane) wallpaper pattern at an admission ticket for the Wembley stadium. The photograph was made under somewhat diffuse illumination, so that the word "valid", located a few millimetres beneath the surface, became illegible.



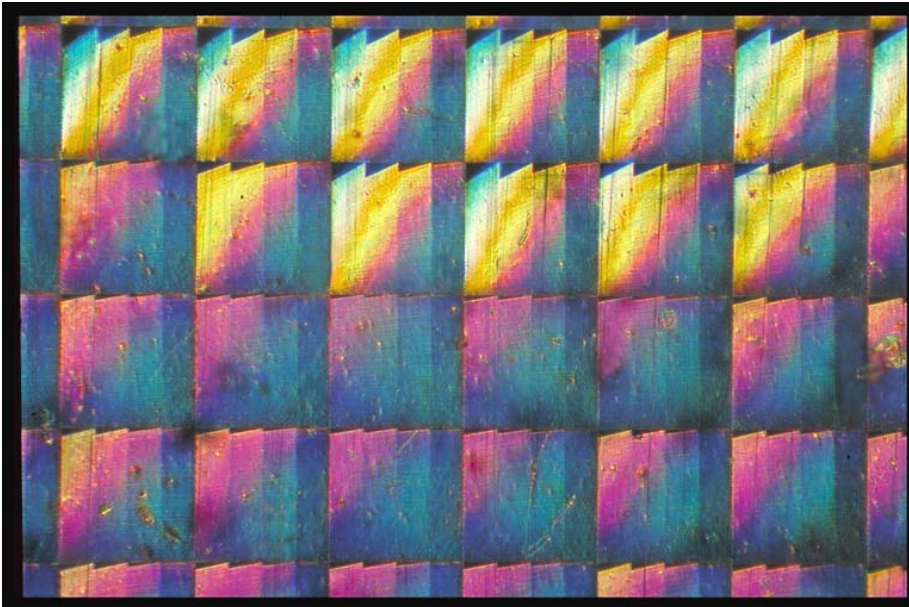
**Figure 4** - A graphical element oriented feature: the Moviegram on the Finnish 20 Mark banknote (Hologram Industries, France).



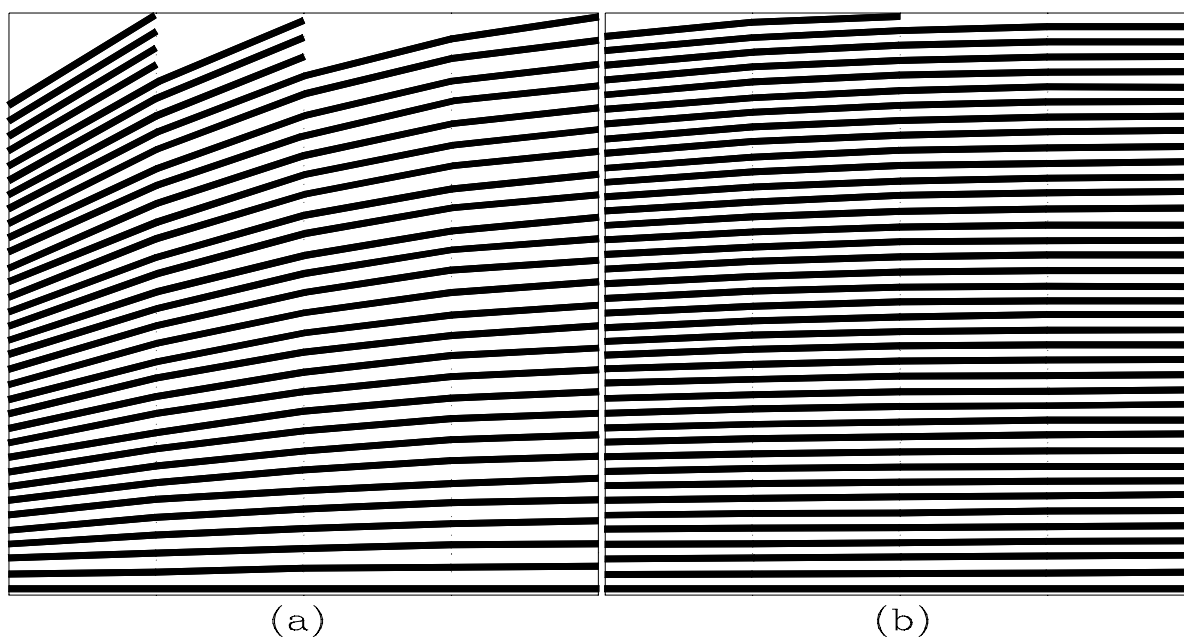
**Figure 5** - A dot oriented feature (2-D) at the periphery of a Microsoft software security feature; the centre of the feature is a hologram (3-D) (Applied Holographics, UK).



**Figure 6** - Microphotograph of the dot-matrix structure. The diameter of the dots is about 20  $\mu\text{m}$ . Together the dots form microtext of 0.15 mm height (Ahead Optoelectronics, Taiwan).



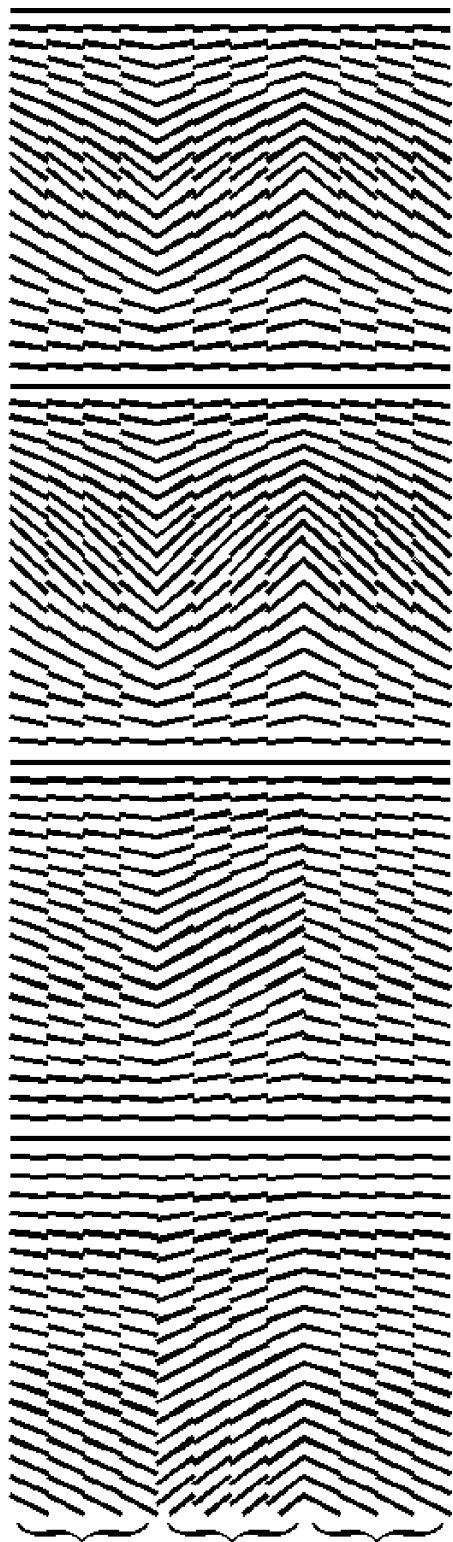
**Figure 7** - Microphotograph of the composition of a pixelgram. The size of the square pixels is 30  $\mu\text{m}$ ; each pixel consists of four subdivisions. (Commonwealth Scientific and Industrial Research Organization - CSIRO, Australia).



**Figure 8** - Schematic illustration of the course of the grating lines in two typical pixels of a pixelgram: (a) a "light pixel" with curved lines (left), and (b) a "dark pixel" with virtually straight lines (right).

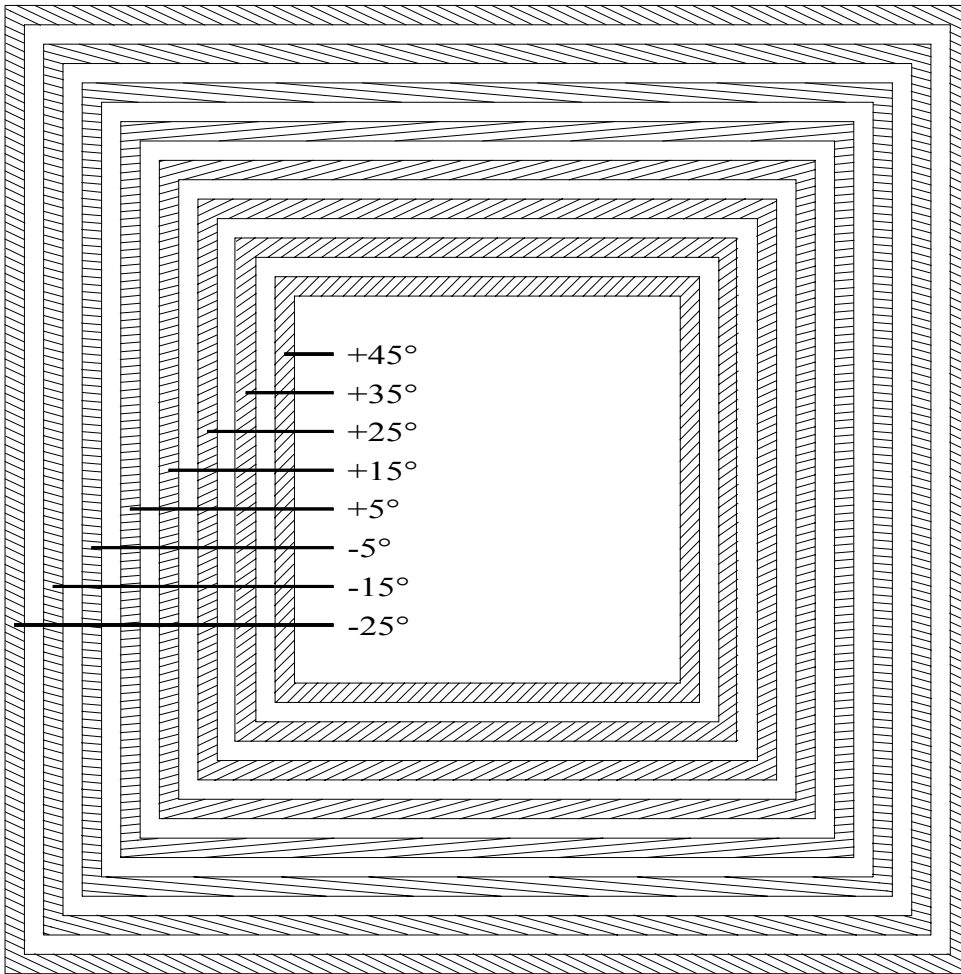


**Figure 9** - A pixelgram with a continuous tone portrait: on tilting the pixelgram, positive contrast (left) and negative contrast (right) are alternately observed. (Commonwealth Scientific and Industrial Research Organization - CSIRO, Australia).

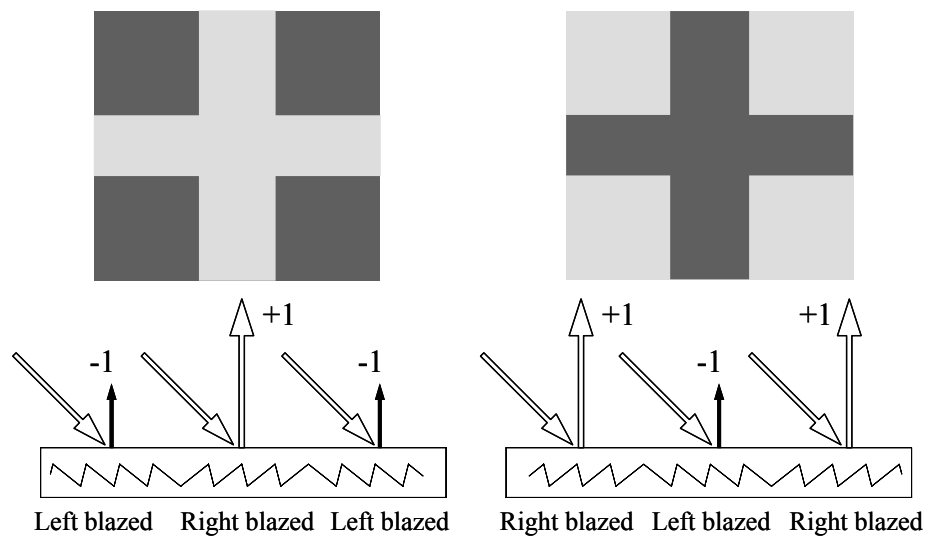


**Figure 10** - Schematic illustration of the course of grating lines in three tracks of an exelgram. The track width is only about  $15\ \mu\text{m}$ . Only a minute part of the length of the three tracks is shown; compare with figure 8. (After a CSIRO leaflet.)

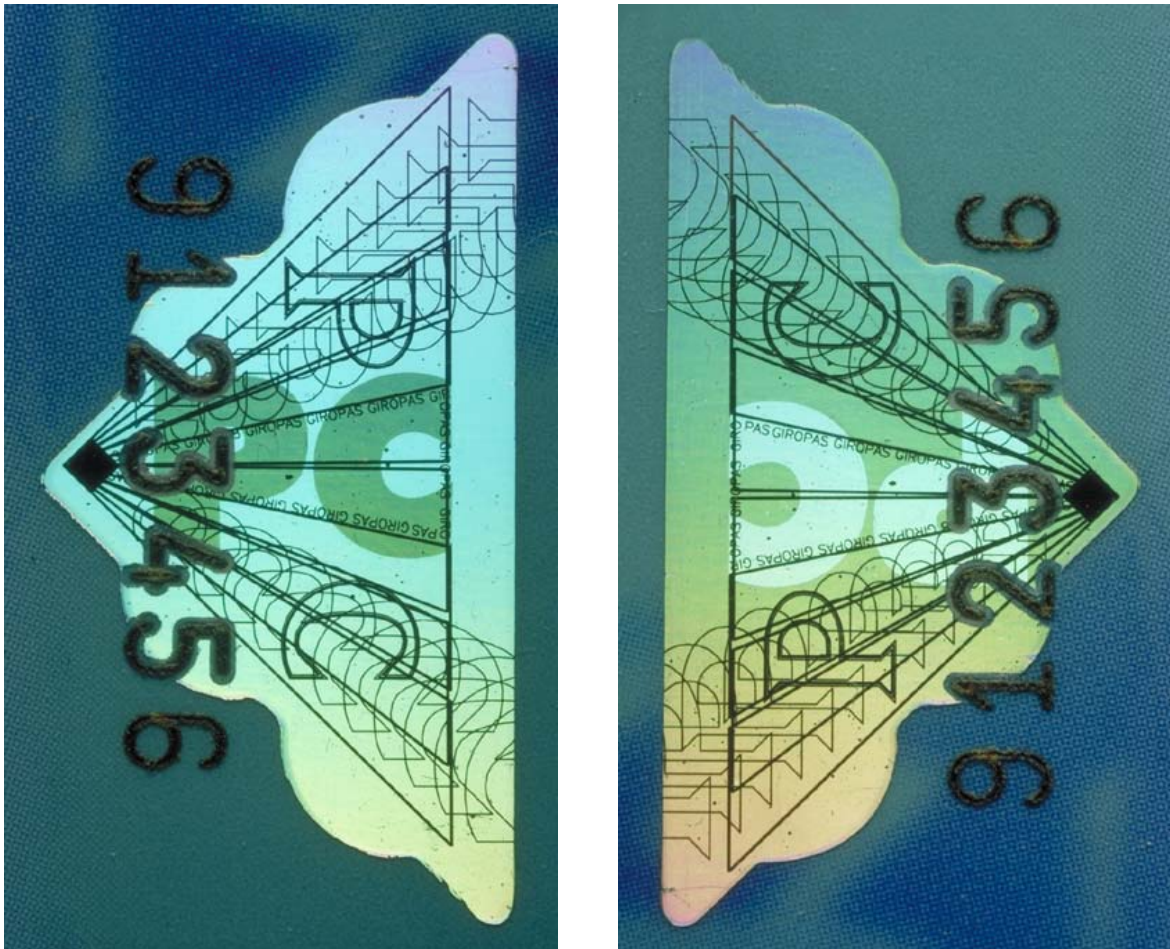




**Figure 11** - The principle of the kinematic effect: an exploding/imploding square: a graphical element consisting of 8 different diffractive elements. The line width of each diffractive element would be a few tens of microns.



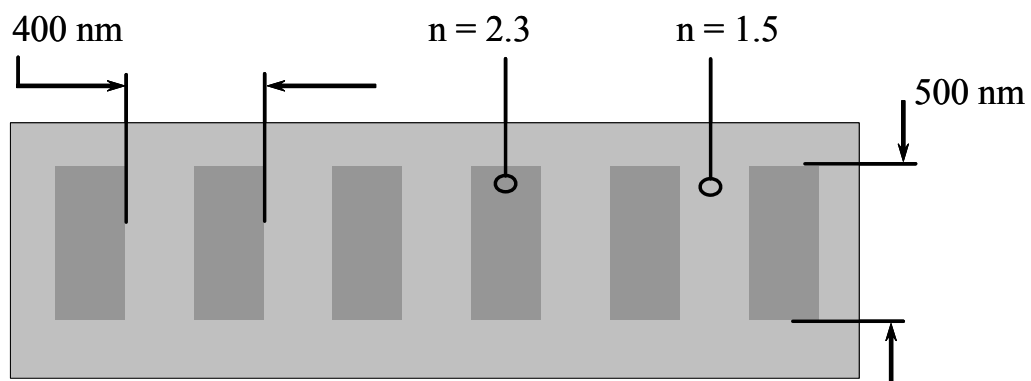
**Figure 12** - The effect of blazed gratings on the first order diffraction. On rotation of the kinegram over  $180^\circ$  in its own plane the contrast swaps from positive to negative.



**Figure 13** - Demonstration of the effect of blazed gratings in the kinegram on the Postbank giropas: plus first order (left) and minus first order (right). (Landis & Gyr, Switzerland)



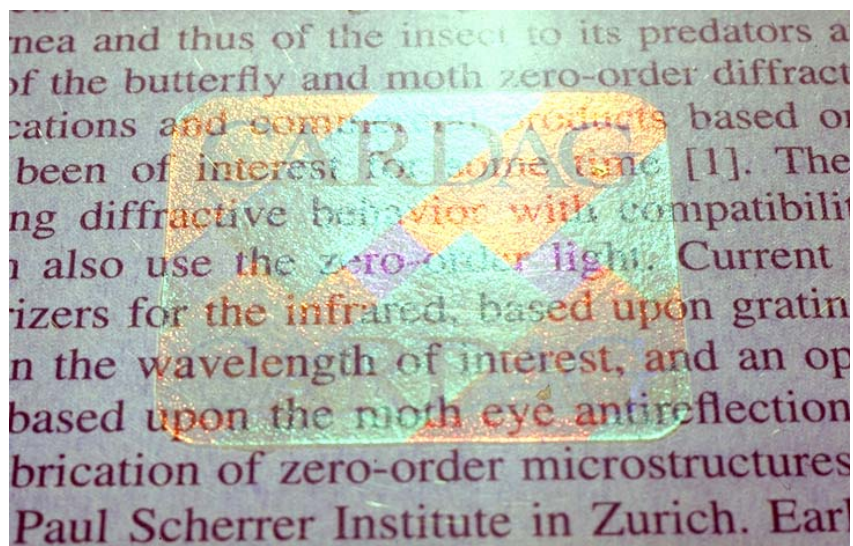
**Figure 14** - Holographic stereogram: Beethoven impersonated on the hologram of the Eurocard in two different postures. (American Bank Note Holographics, USA)



**Figure 15** - Schematic cross-section of a sub-wavelength zero order structure: a high index grating embedded in a low index medium.



**Figure 16** - The DID in reflection at two different angles of observation. Note the green to red and the red to green colour change. (Cardag, Switzerland)



**Figure 17** - The DID is semi-transparent: here it is shown with a text clearly visible in transmission. (Cardag, Switzerland)



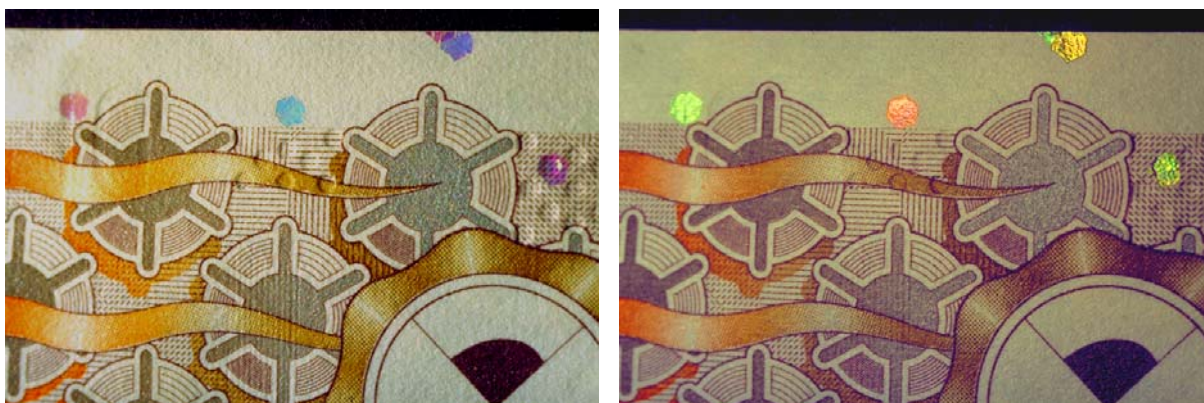
**Figure 18** - All-dielectric stack at two different angles of observation: left diffuse reflection, right specular reflection. (Identocard, Canada)



**Figure 19** - Print in optically variable ink (OVI) with a gold to green shift. Left normal observation, right observation under an angle of  $45^\circ$  with the normal. (Detail of a UK stamp). (SICPA, Switzerland)



**Figure 20** - Three channel volume reflection hologram at three different angles of observation. (Krystal Holographics, USA)



**Figure 21** - Iridescent planchets on the Dutch 100 guilder banknote in diffuse illumination (left) and in specular reflection (right).



**Figure 22** - Polymerized liquid crystal: the Advantage seal at two different angles of illumination. (Advantage Technology, USA)