Protection of High Security Documents

Developments in holography to secure the future market and serve the public

Rudolf L. van Renesse
VanRenesse Consulting[1]

Keywords: holography, document security, nanotechnology, verifier, falsifier.

1 SUMMARY

For many centuries, in different eras and cultures, cruel measures against forgery and counterfeiting have been imposed by document issuing authorities. Although such measures may have been effective, they are now abandoned because of their inhumane character. Alternative measures were sought to render the crafts of counterfeiting and forgery prohibitively difficult. Complex and unique printed designs appeared satisfactory for centuries, until the advance of photography, color copiers and desktop publishing systems in the course of the 20th century. As a consequence, optically variable devices (OVDs), in particular diffractive optically variable image devices (DOVIDs) and interference security image structures (ISISs) made their entrance and successfully defeated widely available photomechanical copying systems.
The pace of the developments increased exponentially: (1) in the time that security features succeed each other, (2) in the numerical expansion of applications and (3) in the advancement of material technology and nanotechnology.
Nanotechnology allowed the production of DOVIDs with a new level of security, by composing these of gratings whose fringe cross-sections significantly deviate from laser interference produced gratings with sinusoidal cross sections. Such gratings display unique optical effects that allow unambiguous first and second line inspection, while they cannot be produced or copied by common laser interferometric techniques.
It may perhaps be stated that the technology has advanced to such a level that DOVIDs can be produced that allow fast and unambiguous first line verification of a document, thus making the inspection of additional security features redundant. This touches the matter of falsifiability and verifiability of security features.

[1] VanRenesse Consulting, Willem de Zwijgerlaan 5, 2582 ED, The Hague, The Netherlands, phone: +31 (0)70 3540333, email: rvr@vanrenesse-consulting.com, website: http://www.vanrenesse-consulting.com/

2 A FEW HISTORICAL OBSERVATIONS ON ANTI-COUNTERFEITING

The following is a reflection on the development of high security documents that struck me while conducting research in preparing this paper. It goes without saying that these reflections cannot involve a limitative treatment of the subject; any attempt to accomplish completeness would require years of research and result in the publication of a series of bulky volumes, and that is not the intention of this study.

2.1 Death penalty

Banknotes are already with us for many centuries. In China, as early as around 800, during the Tang dynasty (618-907) paper currency production commenced as a by-product of Chinese wood-block printing. The notes were issued as certificates in various amounts and were transferable, therefore could be classified as paper money by our current definition. Real paper currency was only introduced early in the Song dynasty (960-1279). Black and red ink colors were used and each banknote had pictorial elements printed of houses, trees, and people. Seals of the issuing banks were applied and secret marks were made on each banknote. At the time, all these features made counterfeiting extremely difficult. An illustration of the oldest surviving banknote of the world, a Chinese Ming Dynasty one Kuan note, is given in Figure 1 [1].

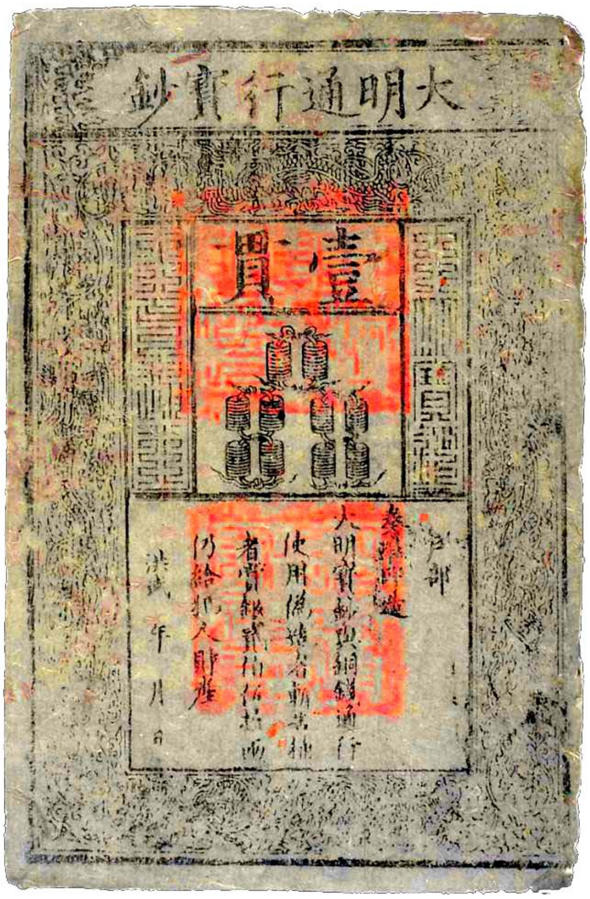

Figure 1 – China Ming Dynasty (1368-1399) wood-block printed one Kuan note (uniface). Standard Catalog of World Paper Money catalog number: China AA10, size 222 x 340 mm.

The six Chinese characters on the top read “Ta Ming T'ung Hsing Pao Ch'ao” (Great Ming Payable Precious Note). The note is hand stamped with two square red chops.

(Source: http://www.tomchao.com/as/as8.html)

For banknote production the wood-block printing technology, the forerunner of letterpress printing, survived for centuries, possibly not only because counterfeiting was difficult at the time, requiring rare professional skills, but also because it was a capital offence.

The crime of counterfeiting in English law was first made a statutory offence in 1562, and was punishable by fine, by standing in the pillory, having both ears cut off, the nostrils slit up and seared, the forfeiture of land and perpetual imprisonment and it was made a capital crime, without benefit of clergy in 1634 [2].

American colonial currency used to contain the warning “Death to Counterfeit”, examples of which are given in Figure 2 and Figure 3.

During the French Revolution (1789–1799), so called *assignats* were banknotes issued by the National Constituent Assembly in France. Originally meant as bonds, they evolved into a currency used as legal tender. As an example Figure 4 depicts a 1792 assignat, also explicitly mentioning death penalty.

For many centuries, in many eras and cultures, cruel and barbarous anti-counterfeiting measures, including death penalty, have been imposed by governments. Death penalty seems to be the longest lasting anti-counterfeiting measure ever, worldwide. Although such measures may have been effective, but this is doubted by many, they were finally abandoned by civilized nations because of their inhumane character.
As a consequence alternative anti-counterfeiting measures were sought in rendering the anti-counterfeiting craft exceptionally difficult. Because the technology of photomechanical reproduction only advanced in the late 19th century, the use of complex and unique image elements has been an efficient protective measure for ages.

Figure 2 – American colonial 5 shilling note (1773) in two printing colors, with warning “To counterfeit is Death” on the reverse. Security features are unique type faces, unique numbering, two color printing and original written signatures of the committee members. Original size 69 x 91 mm. (Personal collection).

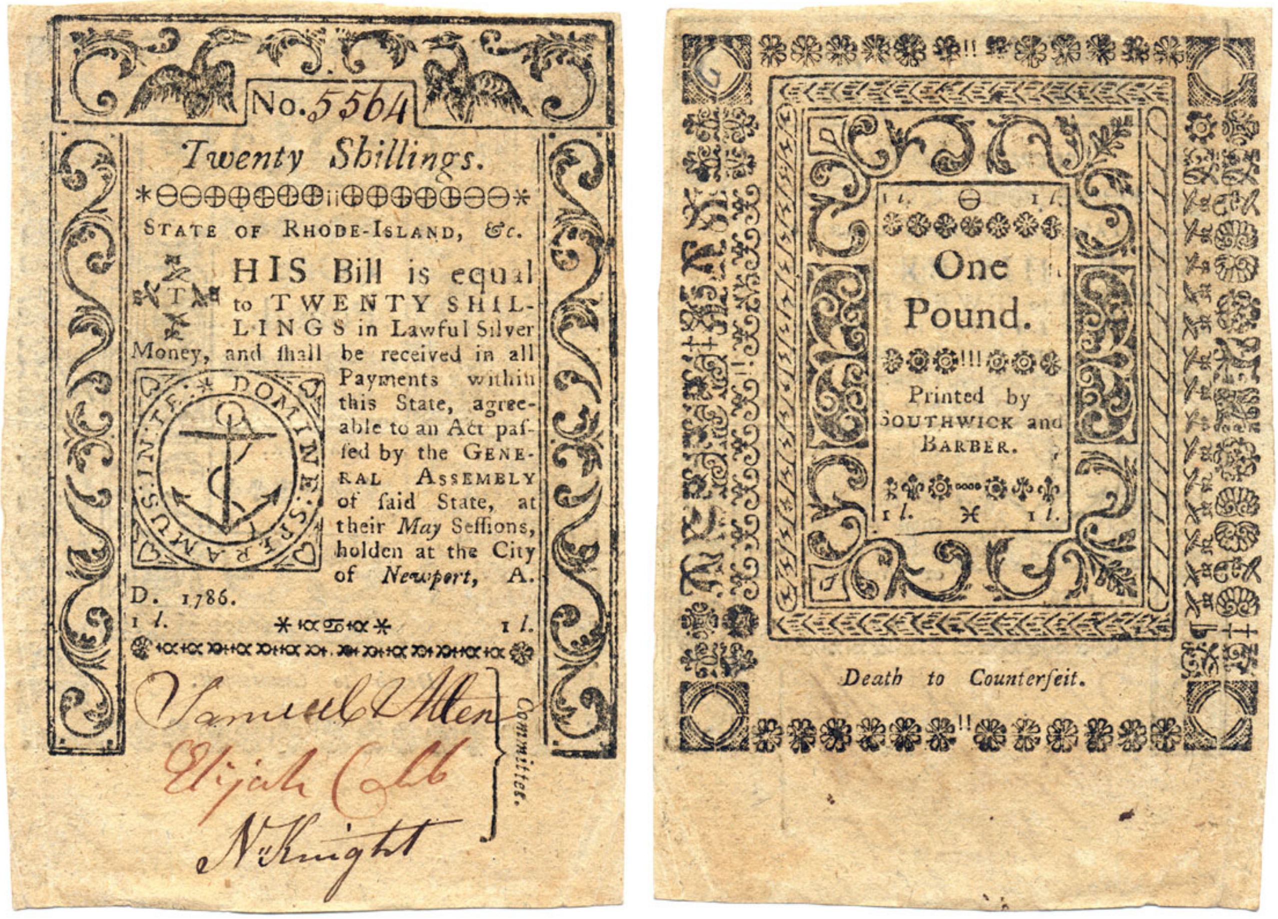

Figure 3 – American colonial 20 shilling note (1786) with warning “Death to Counterfeit” on the reverse. Security features are unique type faces, unique numbering and original signatures of the committee members. Original size 74 x 110 mm. (Personal collection).

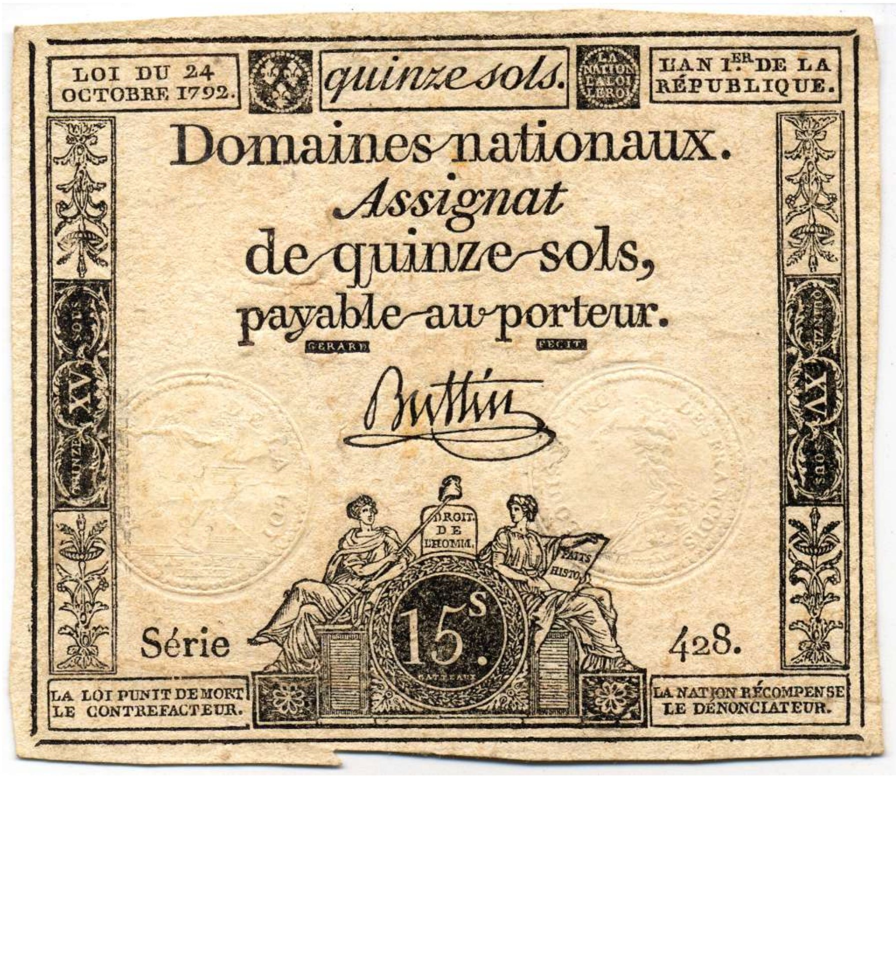

Figure 4 – French assignat of fifteen sols, dated 4 January 1792, stating “La loi punit de mort le contrefacteur” (The law will punish the counterfeiter with death). The assignat has two dry seals as security features in addition to the unique letterpress design.
Original size 79 x 68 mm.
(Personal collection).

2.2 Unique typefaces

An interesting example of such unique image elements is the music typeface. Midway through the 18th century, by order of the upcoming Dutch printing enterprise of Izaak and Johannes Enschedé in Haarlem (The Netherlands), the German punchcutter Johann Michael Fleischmann (1707- 1768) designed an intricate typeface depicting musical notes. Initially the printer was insecure what to do with the weird and wonderful typeface, but about 1795 experiments commenced with the typeface as a secure border printing for valuable documents. In 1797 the County Council of Holland, at the time occupied by the French under Napoleon, issued treasury notes secured by Fleischmann's typeface. No one else had these music types at the time, so they provided perfect black-and-white printing security. In 1814 the just erected National Bank of The Netherlands (De Nederlandsche Bank) issued the first preliminary banknotes, without a watermark yet, but their borders again displaying Fleischmann's musical design as a protection against counterfeiting. The music type persevered for a long time but the printer discontinued the production of banknotes with music type in 1862 because its counterfeiting appeared no longer an insuperable problem. However, the music type was certainly not forgotten and was used for securities into the 1930s. A detail of the music type on a 1901 debenture, together with guilloche-like decorations, is given in Figure 5.

Figure 5 – Letterpress music typeface on a 1901 debenture of the Hollandsche Voorschotbank (image width 132 mm) (Personal collection).

It took about half a century for Fleischmann's "invention" to become of practical use, but this use continued for almost a century and a half. It is safe to say that Fleischmann in the mid 18th century did not foresee the security application of his handicraft and its prolonged use well into the 20th century.

2.3 Holograms

Only about a decade after Fleischmann's music type face was finally abandoned as an anti-counterfeiting device, in 1947 to be precise, the Hungarian-British physicist Dennis Gabor (1900-1979) discovered and demonstrated his revolutionary principle of *wavefront reconstruction*, which method he aptly named "holography", the "writing of the whole" [3]. In 1971 Gabor was awarded the Nobel Prize for his accomplishment. In the mid 1980's I curiously repeated Gabor's optical demonstration of the principle –now called *in-line holography* or *Gabor holography* – using a slide projector with a red filter and pinhole as a light source, and an insect wing as a transparent object. I take the liberty to display the results of my experiment in Figure 6, as a pictorial explanation of Gabor's revolutionary principle. It still appears amazing that the shadow of a shadow constitutes the optical reconstruction of the original object, fine details even reconstructing at a distance of 20 cm.[2]

Did Gabor foresee the implications of his discovery? At the time, and undeniably with admirable foresight, Gabor observed that probably the most interesting aspect of his new method was the application in light optics: the possibility to capture three-dimensional information in one single photographic recording.

Indeed, Gabor's in-line holography, once lasers became available, proved extremely useful in analyzing large volumes of particle dispersions, cavitation phenomena, etc. But, highly coherent light sources lacking at the time, neither Gabor nor the scientific community could possibly foresee the ground-breaking significance of the discovery of holography. Otherwise, in-line holography appears impractical for document security and no applications have been developed for this area thus far.

[2] Also see the entry "Dennis Gabor - Father of Holography at:
http://www.vanrenesse-consulting.com/index.php?t=1162304382&page=photography.htm

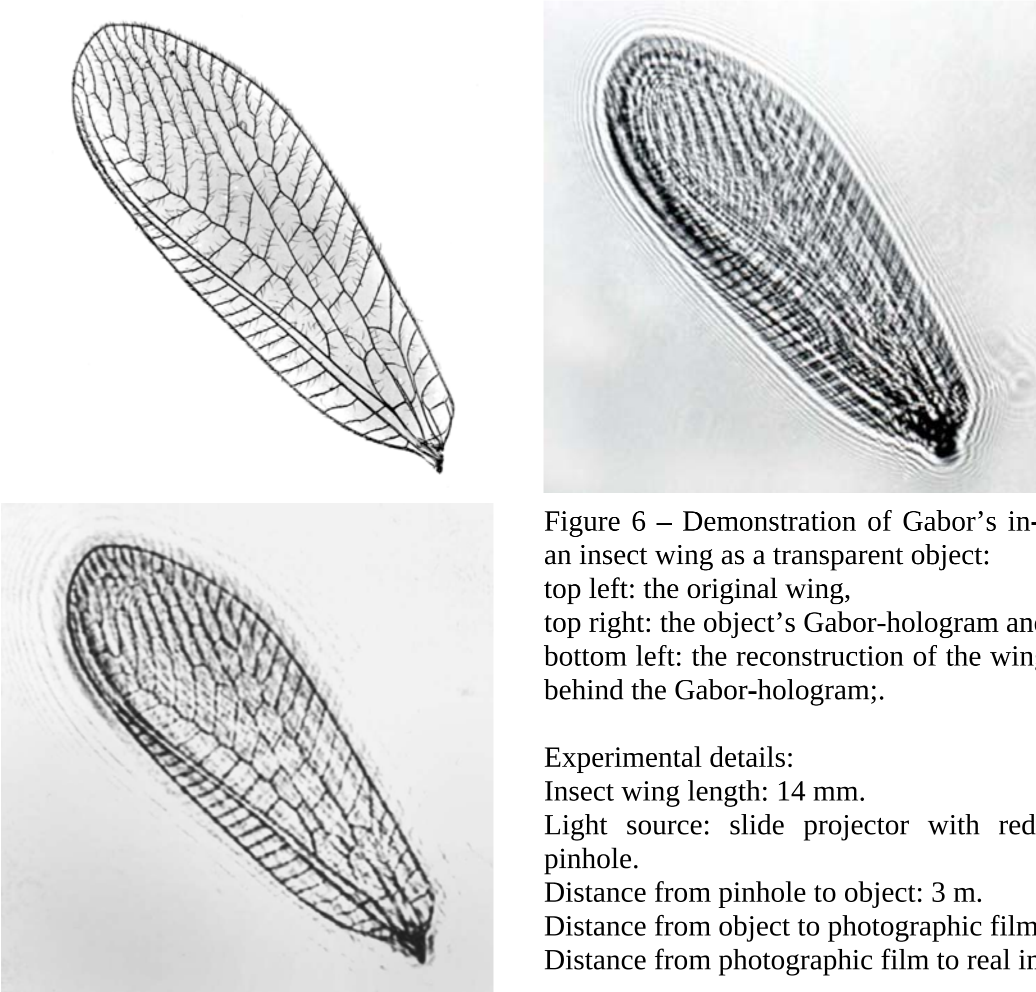

Figure 6 – Demonstration of Gabor's in-line holography with an insect wing as a transparent object:
top left: the original wing,
top right: the object's Gabor-hologram and
bottom left: the reconstruction of the wing from the real image behind the Gabor-hologram;.

Experimental details:
Insect wing length: 14 mm.
Light source: slide projector with red filter and 0.3 mm pinhole.
Distance from pinhole to object: 3 m.
Distance from object to photographic film: about 200 mm.
Distance from photographic film to real image: about 200 mm.

Astoundingly, only one and a half decade later, after the invention of the laser by Theodore Maiman in 1960, the huge implication of Gabor's discovery gradually unveiled. In 1963 Yuri Denisyuk published his paper on *volume reflection holography* [4], and in 1964 Emmeth Leith and Juris Upatnieks published their paper on *off-axis holography* [5], both papers complementing the spatial realm of holography in addition to Gabor's in-line holography technique. Yet, at the time, these new and fascinating developments still appeared unsuitable for document security.
At the time, screen offset reproduction was booming worldwide, but this reprographic technology was only in the hands of a relatively limited number of professionals in the printing industry. High quality color copier machines that could be operated by lay people were not to appear for decades.

Opportunities for the application of holography to document security arose only after Steve Benton's invention of *white light transmission* or *rainbow holography* in 1968 [6] and his development of hologram mass production by recording a surface relief in photoresist and mass-production by embossing the relief in a polymer (1979). Only then, in 1982, two decades after the development of off-axis and volume-reflection holography, MasterCard adds the first hologram to its payment cards and in 1983 Visa follows with the dove hologram.
The hot-stamping of metallized diffractive patches to the smooth and rigid surface of plastic cards appeared to be one thing; adding these patches to the rough paper surface of banknotes that are subject to wear, smudging and wrinkling appeared quite another thing and initially some believed that their application to banknotes was fundamentally impracticable. This appeared an underestimation of the speed of technological progress, because already in 1988 the first diffractive structure turned up on a banknote: the Mozart kinegram on the Austrian 5,000 schilling note. Then, diffractive features started to appear on banknotes in a rapid pace. The growth of DOVID [7] applications on banknotes, presented in Figure 7, appropriately illustrates the trend.

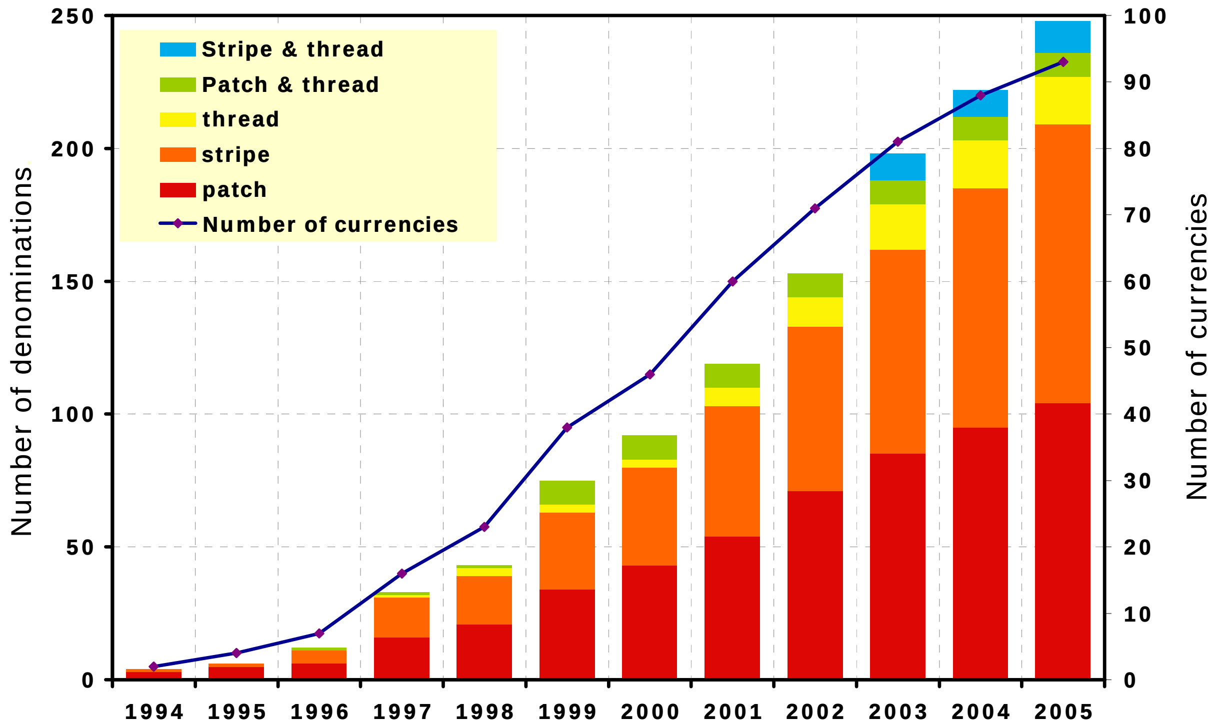

Figure 7 – Number of banknote denominations (bars) and currencies (line graph) with a DOVID applied in the past 12 years (stripe including STRAP). (Courtesy: Astrid Mitchell, Reconnaissance International, UK).

Obsolete currencies are excluded from Figure 7 (e.g. the Austrian schilling and the German mark) as well as commemorative notes. Further, the numbers prior to 1994 would appear statistically insignificant, although they are certainly significant in their marking the advent of a new era. Also, the data in Figure 7 relate only to the year the OVD was first introduced (in several cases, subsequent designs of the same denomination have been issued, also with a DOVID, but these are not included as they would represent double counting).
Also displayed in Figure 7 is the number of currency issuing authorities. The total as of the end of 2005 is 93 currencies. There are some 175 issuing authorities around the world (lower than the number of actual countries because of common currencies such as the euro, the East Caribbean dollar, the West African and Central African francs). But this aside, more than half of the world's issuing authorities now use a DOVID on at least one of their notes.
A paramount growth stimulation factor for DOVIDs was the rise of *digifeiting* [8] in the 1990s as a result of the proliferation of color copiers and desktop systems and the ensuing need for public document verification and the associated disclosure of public features by high security document issuing authorities. Indeed, this trend seems to be reflected by Figure 7. In turn, this invoked a technological drive for high volume wide web production, materials science relating to foil adhesion and foil durability, and demetallization technology [9]. The pace of innovation appeared enormous in this short space of time.

2.4 Identity documents

The written history of passports goes back to about 450 BC. Nehemiah, an official of the Persian King Artaxerxes, asked permission to travel to Judah. The king provided Nehemiah with a letter "to the governors of the province beyond the river", with a request for safe passage through their lands. Obviously, the holder of this royal letter was expected to be Nehemiah, although the letter itself probably provided no proof of that. Many passports today still contain a request to this extent. Such *letters of request*, now called passports, became popular during the reign of King Louis XIV of France (1638-1715). The King granted personally signed documents to his court favorites, which were coined in French "passe port" or “passe porte”, respectively referring to passing through a port or through a city gate. However, the word construction dates back to the early fifteenth century.
Until the end of the nineteenth century personal descriptions on paper, often hand-written, were adequate to identify an individual. It was only during World War I, with the rise of commercial photography, that

photographs were added to such documents of identification. This new technology added significant security to the identification process, because just stealing a “passe port” and passing for the robbed person became virtually impossible. Unfortunately, the binding between document and photograph used to be poor. The photo was generally glued to the document or fastened by means of staples or tubular rivets, as shown in Figure 8. Ink stamps and dry seal cachets (dry embossing) were soon used to further bond photo and document. Because these techniques are quite simple, numerous manners were soon developed by criminal elements to swap passport photographs without the alteration being very obvious.
More recent measures to thwart photo swapping involve the application of hot melt transparent overlay films. But, the photo still remaining a separate item, such laminates do not always appear to significantly thwart forgery and sometimes even assist the forger in his attempts to swap passport photographs. At last, the response was to integrate the passport photograph as a printed or laser engraved image element into the design of the holder page, which approach requires centralized passport production. However, even today passports are issued having physical photographs inserted into the document.

When did DOVIDs enter the passport scene and what was their function? Whereas DOVIDs on banknotes and the like are merely there to protect against counterfeiting, on passports they can and should also shield against forgery of the variable information (passport photograph and personal data).
While the first DOVID appeared on a credit card in 1982 and on a banknote in 1988, in 1985 the first metallized hologram appeared on the passport of Iraq. But this hologram was placed on the inside of the front cover and did not render any protection against forgery. Another example of inadequate implementation of good technology is given in Figure 9. In 1992 the first all-over transparent hologram appeared on the passport of the United Arab Emirates. Growth in the use of holograms on passports is roughly illustrated by numbers: In 2001, 28 countries use DOVIDs in their passports, while in 2006, this number has grown to about 45.
Growth factors apart from technical developments are, amongst others, (1) the development of machine readable DOVIDs, (2) the increase of ID fraud, illegal immigration, terrorism and global travel, (3) the development of international standards and US Homeland Security initiatives. [9].

Figure 8 – Example of the application of tubular rivets and an ink stamp to bind a photo to a Dutch passport identity page.
This passport type was in use between 1950 and 1995. It had a black cover and was sneeringly called “the black rag”, indicating its extremely low resistance against forgery and counterfeiting, which were taking place on a worldwide scale.

Figure 9 – The successor of the “black rag”, was issued in 1995 and lasted until 2001. It still had a separate passport photo, which was protected by a 3M Confirm cover foil. On the back of the holder page (shown here) a kinegram was applied over a corner of the photo, as a further protection against photo swapping. To no avail, because it did not at all stop successful photo swapping. The passport had a red cover and was soon called “the red dud”.

3 THE PACE OF TECHNOLOGICAL ADVANCE

Wood-block printing intricate banknote designs lasted for many centuries. When the more efficient letterpress technology was invented in 1440 by the German Johan Gutenberg and in 1455 by The Dutch Laurens Janszoon Coster, a new technology came available for banknote production, but only in 1661 the Bank of Sweden issued the first banknotes in Europe. Letterpress for printing intricate banknote designs in turn only lasts a few centuries, intricate designs becoming gradually obsolete with the advance of photography during the 19th century. Cameras and film became commercially available at the turn of the century, which in the early 1900s resulted in fraudulently copying of valuable documents. As mentioned, at the same time, advantageously, this allowed the introduction of passport photographs during World War I. With the explosive advance of four color screen offset reproduction technology after World War II, professional counterfeiting of valuable documents in full color became a serious threat, although the number of cases remained relatively limited. Even more serious was the advance of the color copier in the 1980s and desktop publishing in the 1990s, which placed the virtually unlimited ability of copying valuable documents in the hands of the masses. Obviously, chasing a handful of professional counterfeiters or chasing countless digifeiters are very different ballgames. It is no wonder that –in the late 1980s– we see the first appearance on banknotes and passports of DOVIDs and interference security image structures (ISIS) based on light interference in thin films.

The trend is obvious, the pace of technological advance, measured by centuries in ancient times, becomes measured by decades in the late 1800s and early 1900s, and finally by years in the late 1900s and the early years of our new millennium. This exponential stepping up of the historic pace is of course well known and counts for all major technological fields. The preceding sections only present a small fraction of all relevant developments.

3.1 The Expanding Universe of Holography

The theme of the current Holopack**.**Holoprint Conference “The Expanding Universe of Holography” does not only refer to the sheer numerical expansion of DOVIDs and the rapidity of this expansion as illustrated in Figure 7. It is important that security is based on a variety of novel and diverse technologies in order to provide adequate resistance against forgery and counterfeiting. Therefore, this current theme should specifically involve the pace of the technological progress, without which this expanding market would simply not exist. This advance involves two crucial technological trends, which also determine the future of holographic security.

- Material technology
  The moving away from stand alone holographic patches through advances in substrate technology, thread technology, foil technology and stripe technology.
- Nanotechnology
  The development of sub-wavelength detail fringe structures, with non-sinusoidal cross sections, generating unique optical effects that are very difficult to originate and virtually inimitable, but allow relatively easy first line inspection.

3.2 Material technology

Diverse advances in material technology allowed the realization of full page high refractive index DOVID overlays on identity documents, large and durable DOVIDs highly integrated in banknote designs, and the development of novel security features, including transparent windows in paper substrates and high resolution demetallized image elements in tight register with the diffractive imagery (Kinegram *zero.zero*® technology [10]). Mention must further be made of De La Rue’s Optiks™ diffractive threads, in widths up to 18 mm, that are embedded in paper substrates so that they can be observed on both sides of the document. This is unlike conventional windowed threads that are visible from one side only. Another Optiks™ aspect is the inclusion of a clear see-through aperture, void of paper fibres, so that the exposed demetallized thread can be easily viewed in transmitted light [11].

Transparent windows allow the incorporation of a profusion of novel security features, including Securency’s WinDOE™ in a polymer substrate [12] and the development of transparent windows in paper substrates signifies a major achievement: Louisenthal's *Verifeye®* [13] and Kurz' *Modular Banknote Concept* [14], which was a forerunner to its latest development with Giori (*WindowCut®*). Successful counterfeiting or simulating such paper-based windows should be a difficult task if practicable at all.

The development of novel stripe technologies can be partly illustrated by the history of the STRAP feature (**S**ystème de **T**ransfert **R**éfléchissant **A**nti-**P**hotocopie) of the Banque de France [15]. The STRAP foil was first applied in 1992 to the 10,000 francs note of the Central Bank for the West African Monetary Union (Banque Centrale des États de l'Afrique de l'Ouest - BCEAO). The BCEAO comprises Benin, Burkina Faso, Ivory Coast, Guinea Bissau, Mali, Niger, Senegal and Togo, all of which share this currency. This STRAP foil consisted of a line offset and intaglio overprinted reflective metallized stripe, yet without iridescent elements. This stripe turns black in digital copies as illustrated in Figure 10 and Figure 11.
A diffractive version of STRAP, appearing as a string of diffractive patches rather than as the continuous diffractive stripe found on other currencies, was issued in 2002 on the 5,000 and 10,000 franc notes of the Banque des États de l'Afrique Centrale (BEAC) serving the countries of the CEMAC region (Communauté Économique et Monétaire de l'Afrique Centrale), which comprises Cameroun, Congo, Gabon, Guinee Equatoriale, Republique Centrafricaine and Tchad (Figure 12).
In the latest STRAP version, called *STRAP Perfection*, Kinegram zero.zero® technology is integrated, allowing exact register between demetallized and diffractive design elements, while the latter can in turn be accurately registered with the printed design as well as with a transparent window cut in the paper substrate [10]. An example of STRAP Perfection with register between transparent windows and diffractive foil is given in Figure 13. In turn, an example of register between print and diffractive foil is given in Figure 14. The latter figure displays an achromatic image composed of low frequency left and right blazed gratings. Such achromatic blazed gratings are found on the 1999 Singapore currency and a description of this blazed grating technology is given by Staub and Tompkin in 1998 [16]. For further nano-technological aspects of diffractive security structures see section 3.3.

Figure 10 – STRAP foil on the 10,000 franc BCEAO 1992 note. The foil turns black in a digital copy.

Figure 11 – STRAP foil on the 50 French franc 1993 note. In specular reflection (left) and in a digital copy (right). Foil width 3 mm.

Figure 12 – STRAP foil on the 10,000 franc 2002 note of CEMAC: display of first order diffraction.
Image width 64 mm, foil width 10 mm.
This diffractive strap also appeared on the 5,000 franc 2002 note.

Figure 13 – STRAP Perfection with zero.zero® technology (19 x 33 mm detail): in first order diffraction (left) and in transmission (right), showing register between demetallized diffractive foil and transparent OVD windows. Foil width 16 mm. (Sample courtesy of Leonhard Kurz GmbH & Co. KG, Germany).

Figure 14 –Kurz Modular Banknote Concept with zero.zero® technology (detail 20 x 24 mm): register between printing and a diffractive foil with achromatic blazed gratings (*white diffractive watermark*) illuminated from top (left) and illuminated from bottom (right). (Sample courtesy of Leonhard Kurz GmbH & Co. KG, Germany).

The Verifeye® paper-based transparent window is illustrated in Figure 15. The window is created during paper production and, as a result, it is characterized by the extension of paper fibers into the transparent window. This can be verified with the naked eye and serves as a security feature in itself because it renders a clear distinction with mimicked windows that are cut into paper by counterfeiters. In this respect the Louisenthal window differs from the Kurz window, the latter appearing to be cut after paper production.

The current Verifeye® window in the Bulgarian 20 Leva note consists of a pattern of green-to-blue shifting liquid crystal ink bands, printed on the front and a pattern of black “20”s printed on the reverse. When observed against a dark background the iridescent liquid crystal ink reflection prevails, while against a light background the “20”s stand out in transmission. This type of first inspection is considered easy because light and dark backgrounds are generally quickly found in most available light environments. Observation with a set of right handed (RH) and left handed (LH) circular polarizers allows checking for the presence of the circular polarization effects of the liquid crystal ink. The OVD strip on the Bulgarian note further contains a few reflective/diffractive patches (shown in Figure 15), while the note further contains the denomination printed in magenta-to-green shifting optically variable ink (OVI) on the front and a 2 mm wide red-to-green shifting windowed thread both features being ISISs (not shown in Figure 15). Considering, this note may be regarded as a rare showcase of OVDs.

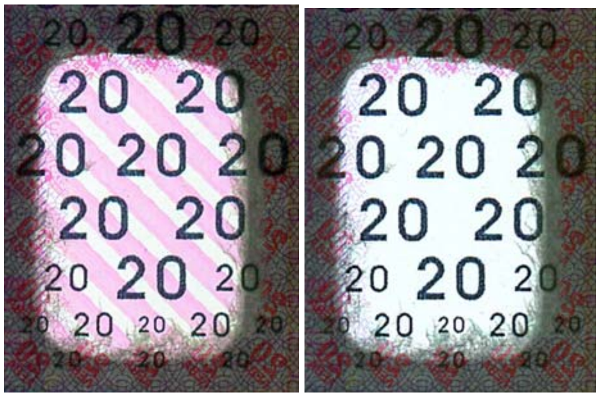

Figure 15 – Verifeye® transparent window feature in the 20 Leva Bulgarian paper-based commemorative note (2005): in diffuse reflection including first order diffraction (left) and transparent window details (15 x 25 mm) in transmission in RH circularly polarized light (center) and LH circularly polarized light (right).

3.3 Nanotechnology

DOVIDs achieve a further level of security when they are composed of gratings whose fringe cross-sections significantly deviate from the usual laser interference produced gratings with sinusoidal cross sections. Such deviating gratings can display unique optical effects that allow unambiguous first and second line inspection, while they cannot be produced or copied by common laser interferometric techniques and resist holographic copying. The critical details in these gratings are so minute that a production resolution of about 50 nm or better is required to achieve adequate optical effects, which obviously involves manipulation of matter on the nano-scale.

The first nano-secure DOVID –the patent dates back to 1989 [17]– was composed of blazed gratings, which sawtooth shaped fringes diffract plus and minus first diffraction orders with significantly different brightness (Figure 16). This new development allowed the design of diffractive images that display a positive-negative swap on an in-plane rotation of 180° as shown in Figure 17. These features were later coined *diffractive watermark* and today they are part of all kinegrams® (OVD Kinegram Corp., Switzerland). The first diffractive watermark appeared on the Dutch Postbank cheque in 1995, it first appeared on banknotes in 1996 (DM 50, DM 100 and DM 200) and on the Bosnia passport in 1998.

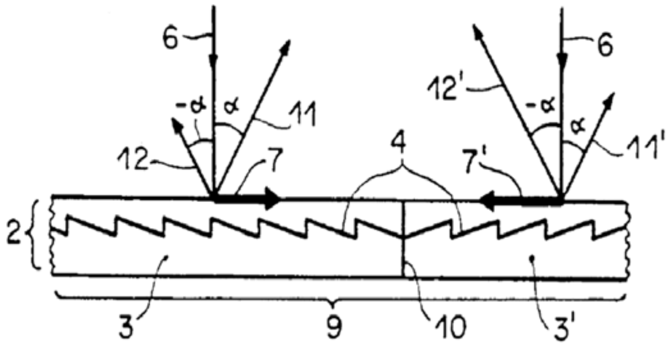

Figure 16 – Left and right blazed gratings (from EP 0360969 A1).

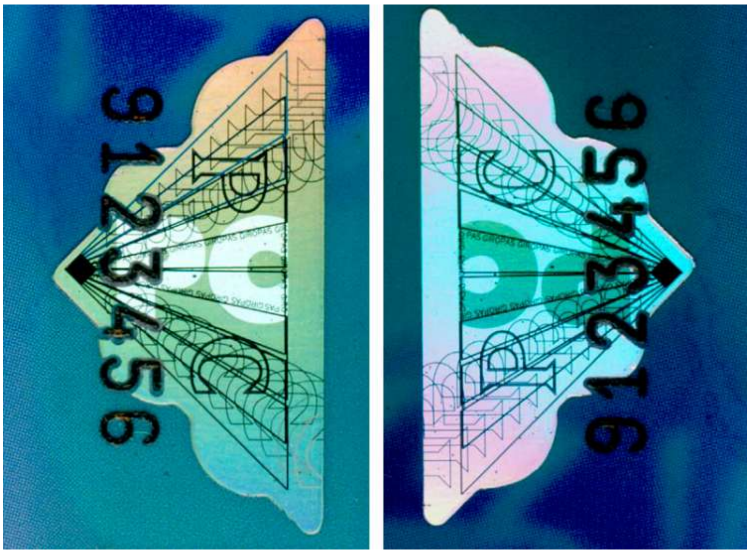

Figure 17 – Diffractive watermark in Dutch Postcheque kinegram®, issued in 1995, displaying a contrast swap on 180° rotation.

A joint endeavor of the Paul Scherrer Institute (merged with CSEM in 1997) and CARDAG AG (both in Switzerland) started in 1988 and led to the development of a zero-order nanostructure security device (the patent dates back to 1982, see Figure 18). This *zero order device* (ZOD) consists of a high refractive index block-shaped grating with sub-wavelength periodicity, embedded in a low-index matrix, and it displays striking color swaps on a 90° in-plane rotation as shown in Figure 19. The reflected light is linearly polarized, which allows additional second line verification. The first conference publication on ZODs appeared in 1990 [18]. Hologram Industries (France) currently produces the ZOD, which is coined *diffractive identification device* (DID®). The DID® found its first commercial application in 2003 for administrative certificates linked to the Ministry of Agriculture in Ukraine, and first appeared on a passport (the Slovakian passport) in 2004. The DID® has not been applied to currency yet.

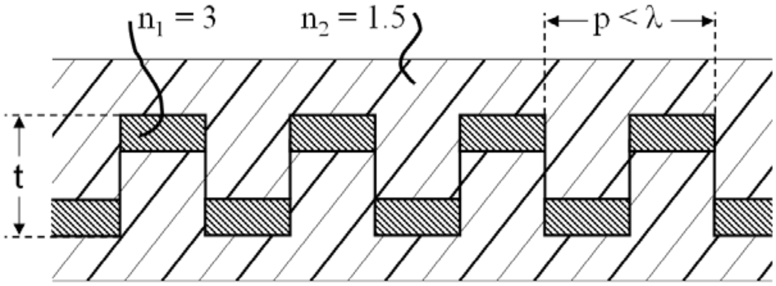

Figure 18 – Zero order diffraction grating (after US 4484797).

Figure 19 – DID® overlay with alphagram in first order diffraction (top left), and in zero order reflection displaying color swaps on 90° rotation (bottom left and right). (Sample courtesy of Hologram Industries, France.)

Again another diffractive nanostructure was published by James Cowan of Polaroid Corp. in 1989 [19], which feature was coined AZTEC, derived of the words “diazo photoresist technology”, but more obviously referring to the resemblance of the grating’s cross section with the stepped shape of Mesoamerican Aztec pyramids (see Figure 20). The Aztec structure combines the properties of ISIS type Denisyuk holograms (volume-reflection holograms) with DOVID type surface relief holograms. The visual characteristics of the Aztec structure are similar to the volume hologram, in that a single waveband is reflected, its colour depending on the viewing angle, rather than displaying a dazzling range of diffracted rainbow colours. From an ergonomic point of view, a simple colour scheme can be an advantage. A further advantage is that Aztec holograms can be mass-produced by casting, contrary to volume-reflection holograms, each of which must be separately recorded and processed.
Combinations of single colours can be incorporated in a single master, yielding distinctive visual effects. It has also appeared possible to create blazed Aztec structures, which display colour swapping effects that Denisyuk holograms cannot produce (Figure 20). Contrary to rainbow holograms, which only display horizontal parallax, Aztec holograms display full 3D parallax. Aztec holograms have not yet found commercial applications, but they inevitably will.

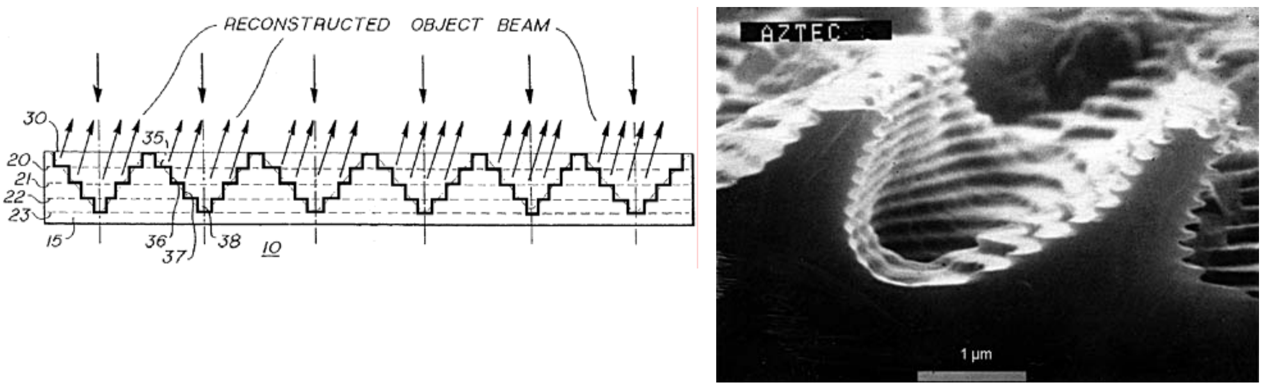

Figure 20 – Aztec grating structure (from US 4874213) (left) and SEM photograph of a blazed Aztec structure (right) (Courtesy of SEM photograph: James Cowan).

In 2003 New Light Industries, Ltd. (USA) filed a patent on a security feature with a surface relief structure that has both polarizing and diffractive properties [20]. The feature is coined Polaris™ and consists of a sub-wavelength period block-shaped grating, modulated with a low-frequency diffraction grating, as shown in Figure 21. The high frequency grating is a ZOD, displaying 2D vivid colour swaps in polarized light, while the low frequency grating displays first order type DOVIDs (Figure 22). By creating low-frequency gratings in different areas, with different grating orientations and frequencies, it is possible to design diffractive images similar to dot matrix holograms, displaying kinetic effects, colour effects, three-dimensional effects and angle-multiplexed effects.
The patent further proposes high frequency gratings that are frequency modulated with "chirped" features of which the periodic variation is greater than the wavelength of light, to render diffractive effects equivalent to those of blazed gratings (see Figure 23).

Figure 21 – A zero order type block-shaped grating, amplitude modulated with a low-frequency sinusoidal first order grating (after US 6,975,765).

Zero order reflection Horizontal polarization | Zero order reflection Vertical polarization | 1st order diffraction Unpolarized

Figure 22 – Polaris™ feature illuminated from the top (top row) and from the side (bottom row). Sample courtesy of Steve McGrew, New Light Industries, USA (image size 10 x 10 mm).

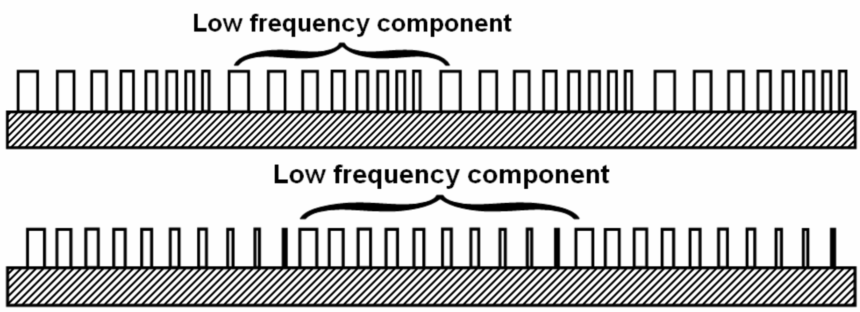

Figure 23 – High frequency gratings, frequency modulated to produce blazed grating type diffractive effects (after US 6,975,765).

3.4 First Line Security: verifiers and falsifiers

Security features can be divided into falsifiers and verifiers [21]. If *verifiability* is defined as the state of being confirmable as true (genuine) and *falsifiability* as the state of being confirmable as false, it can be upheld that many first line security features are merely falsifiers. An example of a falsifier is the front-back see-through register feature. Is a banknote having front and back printing in perfect register genuine? Not necessarily, because counterfeits exist with excellent front-back register. In fact, this see-through feature is sometimes advantageously used by counterfeiters to register front and back printing. Of course, if front and back appear out of register, the note is falsified, but when in register it is not verified. Another example is the tactility of intaglio printing. Line offset counterfeits exist with pronounced tactile relief, neatly embossed in register with the –intaglio imitating– line offset printing. Counterfeiters have no intaglio presses, but they can accurately emboss the paper substrate. The absence of tactility falsifies the note unless it is extremely worn, but its presence does not verify it. How many falsifiers are we prepared to examine in first line before we are convinced that a note is genuine? Of course, falsifiers present definite hurdles that the counterfeiter must try to jump, but they do not successfully serve the public in first line inspection.

This touches a thorny subject. Ian Lancaster recently proposed that DOVIDs function most appropriately at the second-line inspection, which should be undertaken by trained examiners equipped with simple tools to facilitate this inspection. Lancaster believes “that it has become clear that the public do not either care enough or have adequate knowledge to undertake even first line inspection” and proposes “that it is unreasonable to expect the public to inspect an authentication device, and that anyone who is expected to conduct an inspection needs to be trained and equipped appropriately.” [22]

Practice seems to prove Lancaster right: the public does not generally inspect their banknotes. Does the public really not care or just have faith in their currency? Whichever the case is, statistics show that such faith is justified. The chance that an individual receives a counterfeit is extremely remote, and thus inspection of anything other than the face value (or even just the note’s colour) seems a waste of time. Does the public not have adequate knowledge? I agree, it does not, although Hans de Hey shows that there is some improvement in case of prolonged education [23]. But this lack of knowledge cannot be entirely attributed to a lack of public interest, it must be attributed to a lack of insight of the issuing authorities in the first place. It is irrational to expect the public to inspect more than one single security feature, although this is exactly what the issuing authorities unceasingly request. The public can be expected to just understand and remember one single ergonomic verifier, and that’s only reasonable.

Therefore, it is also irrational to base the security of DOVIDs on the image complexity of their design, however tempting it may be to devise massive, irreproducible detail into the diffractive image because technology allows it: this only serves expert 2nd and 3rd line inspection, it is of no use to the public whatsoever and does scant justice to the potential of DOVID technology. If the practical use of DOVIDs should indeed be limited to 2nd and 3rd line inspection, as Lancaster proposes, this use will certainly not attribute to the noteworthy expansion of the universe of holography.

What then will really propel the universal expansion of DOVIDs? It is their verifying power. Documents that do not carry one single verifier do not allow the consumer to adequately inspect them, and even prolonged public education is not going to ever significantly improve this.

Obviously, it would be ideal to have one single ergonomic verifier available that permits first line examination in a glimpse. In short, effortless and reliable verifiability on all sorts of valuable documents, banknotes, passports, etc. Optically variable devices, such as DOVIDs, can perform such first line verifying function by means of nanostructures that display unique optical effects, that can be easily, quickly and inconspicuously verified, but cannot possibly be successfully imitated.
It is up to the security industry to realize this ideal; hiding behind the inexperience of the public is unacceptable. There can also be no hiding behind the statement that relying on one single security feature entails a security risk and that inspection of several features is required. Many industries have proclaimed to offer invincible first line security solutions, the DOVID industry no less. Noblesse oblige!
If a high security document becomes a showcase of security features –such as the Bulgarian note depicted in Figure 15– the public cannot cope. If different high security documents rely on different features, the public cannot cope. As Goethe said: „In der Beschränkung zeigt sich der Meister“.

4 INTERNATIONAL STANDARDS

Essential paragraphs of the current ICAO Travel Document Standards and EU Travel Document Standards are worded to recommend or even require the use of DOVIDs:

> **ICAO Travel Document Standards**, Paragraph 5.3.2, Appendix 1, Section III Security Standards for MRTD of ICAO Doc9303, Part 1 Passports, 6th edition:
> “When the biographical data page of a passport book is protected by a laminate or overlay, an optically variable feature (preferably based on diffractive structure) should be integrated into the page. Such a feature should not affect the legibility of the data …. The inclusion of a diffractive optically variable feature is recommended to achieve an enhanced level of protection against reproduction.”
>
> **EU Travel Document Standards**, EU Council resolution (EC) No 2252/2004, Minimum Security Standards for Passports & Travel Documents, Annex Section 4:
> “An optically variable (OVD) or equivalent device, which provides the same level of authentication and security as currently used in the uniform visa format, shall be used on the biographical data page and shall take the form of diffractive structures which vary from different angles incorporated into the hot-sealed or an equivalent laminate (as thin as possible) or applied as an OVD overlay, or stickers on a non-laminated paper inside page (as metallised or partially demetallised OVD with intaglio overprinting) or equivalent devices.”

Obviously, the wording of these international standards entails a growth factor for the DOVID industry. However, it is observed that any standards or programs of requirements shall be essentially neutral and not explicitly recommend, let alone demand solutions by incorporating specifications. This is only reasonable because any explicit specification inherently limits the realm of possible solutions and it shall be left to an independent proposing party to formulate solutions for the problems indicated by the customer. Diffractive structures may well be the ultimate solution to existing and future document security problems, but standards shall not explicitly reflect this.

5 ACKNOWLEDGEMENTS

I am indebted to Astrid Mitchell of Reconnaissance Int. (UK) who provided a wealth of information for this paper and took ample time to discuss it with me.

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