Luminescent Security Properties of Banknotes

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Abstract

Since the beginning of human civilization, whenever any item has gained some value a fake version has also appeared shortly afterward on the market. This endless combat between the owner of the original product and the counterfeiter still continues to our day. Better and more affordable color copiers have added a new dimension to the forgery. Appearance of the color scanner to the market has also made the task to counterfeit the banknotes a lot easier. There are many methods to render the color copier's or scanner's task more difficult or impossible. One of these methods is to utilize luminescent (fluorescent or phosphorecent) pigments that change color under non visible light sources.

The main features to utilize the use of the fluorescent phenomenon in banknotes are paper fluorescence (non fluorescence), fluorescent security fibers and fluorescent printing. Inks, fibers and planchettes based on organic fluorescent substances are regularly used to produce security elements. The luminescence of such elements is absent in white light but is revealed under actinic radiation.

One method is to combine fluorescent and phosphorescent materials in a security element. To discriminate between fluorescence and short-lived phosphorescence a portable phosphorescence detector can be used. In this study we measured the luminescence radiation spectra of the different kinds of euro banknotes and analyzed the luminescence emission spectra. We also tested the durability of banknote luminescence and analyzed the results. Novel luminescence spectral data will be provided.

Introduction

When examiners inspect a banknote, they compare the characteristics of the security features to the characteristics of the reference that they or the machines designed for this purpose memorize. There are three levels of security inspection depending on the environment in which the banknotes are verified.[1] Reliable first-line authenticfication guarantees limited counterfeit document diffusion and public confidence in the banknote. Second-line authentification limits acceptance of forgeries by shopkeepers and deters potential counterfeiters. Third-line inspection eliminates forgeries from circulation. There are at least three requirements that security features must satisfy:

1. The interpretation of the security features must be obvious and security features must be durable.
2. The security features must be integrated in the banknote and manufacturing process has to be secure.
3. The cost of security features must be compatible with the market.

Security features that complement the watermark and can be examined by the public in first-line inspections include standard features as planchettes and fibers and are usually based on luminescent inks, fibers or grains. The subject of this study is luminescence (fluorescence or phosphorescence) in Euro banknotes.

Luminescent Effects in Banknotes

Luminescence is the emission of radiation by an atom or molecule in the course of a transition from a higher to a lower state of energy. To acquire a high energy state, the atom or molecule has to absorb energy through the process called excitation.

The primary type of luminescence used for security features is photoluminescence, which consists of two types: fluorescence and phosphorescence. The phenomenon continuing less than one millisecond after excitation is called fluorescence. The term phosphorescence is used when the luminescence continues longer than one millisecond. The most widely used fluorescent security products emit light in the visible spectrum when excited with long ultraviolet radiation (wavelength = 365 nm) and products that emit visible light after excitation with infrared radiation are also used. Numerous organic and inorganic substances are described in the available literature.[2] The choice depends on the requirements such as light fastness of the pigment, detection means, cost and so on.

There are many ways to implement luminescent substances:

1. *Ink.* An ink can be made by mixing a luminescent pigment with a binder. This kind of ink is used to print security threads of planchettes.
2. *Fibers.* The luminescent pigment can be attached into a polymer that gives fibers after spinning. Other possibility is to absorb the pigment in fibers by a diffusion process.
3. *Grains.* The luminescent pigment also exists as 10-30 μm grains, which, mixed with the pulp like a filler, yield a paper that displays colored spots under ultraviolet excitation.

To make the process of counterfeiting even more difficult, luminescent compounds may be mixed to produce special effects. For example, it is possible to mix fluorescent pigments with phosphorescent pigments. Under ultraviolet excitation long- and short-lived emissions are combined and after termination of excitation, only the phosphorescent light remains. This kind of effect may also be obtained through the use of pigments that show dual fluorescence with longwave remanence. But for this kind of luminescence detection, special equipment is required. Current portable ultraviolet sources are inexpensive and suitable for detection in most locations.

A sufficient security level requires durable luminescent pigments. Organic pigments with a large difference between excitation and emission wavelengths (for example, ultraviolet to orange) suffer molecular stresses that tend to shorten their effective lifetime. In addition, pigments are recommended that are difficult to find on the market and hard to imitate with readily available products. In contrast, very durable blue fluorescent optical whiteners, used in washing powders, have a large diffusion on the market. The durability luminescence also requires that nothing obstructs the exciting radiation from the security feature.[1]

Observations of Banknote's Security Features in New Euro Banknotes

Security fibers are invisible in white light and fluoresce under ultraviolet irradiation. Although these fibers are very fine, their luminous fluorescence is very noticeable. Imitations are frequently drawn or printed, quite some of them being truly deceptive. Sometimes imitations are even drawn with fluorescent inks that are visible in white light. Luminescent security fibers are widely used in new Euro banknotes.

During paper production tiny disks of about one millimeter diameter can be added to the paper furnish. These disks are called planchets.[3] Planchets can be colored, like in Canadian currency or colorless and only visible under ultraviolet irradiation. Fluorescent planchets may appear colored in visible light as well. This security feature is more difficult to counterfeit.

Fluorescent printing can be either transparent and invisible in white light or it can be absorptive. For example, Euro banknotes carry many fluorescent offset images that are invisible in white light. This is the one of the most used security feature in Euro banknotes.

Fluorescent security features can be combined with other security features such as optically variable devices (OVD's) (holograms, multiple gratings, thin films, pearl luster inks and so on).[4] By combining these security features to each other, we get even more secure protection against counterfeiting. For example in 5 and 20 Euro banknotes the combinations of fluorescent green color pigments and OVD's are used.

Banknote paper is so called "dead" paper, that is, it is non-fluorescent. Most commercial papers contain whiteners that show strong bluish fluorescence under ultraviolet irradiation. However, a genuine banknote will exhibit notable fluorescence if washed and having absorbed a significant amount of the whiteners present in laundry detergents. There is a strong possibility that this can cause misunderstandings when a person accidentally washes his/her banknotes with the laundry and tries to use the currency in a shop. This is also a problem with Euro banknotes.

Spectral Fluorescence Measurements of Euro Banknotes: Materials and Methods

In this study we measured Euro banknotes' radiance spectra (fluorescence emission) to define what kind of luminescent pigments are used in euro banknotes and what kind of emission spectra luminescent pigments have. In addition we also did a small stress test to define how banknote's luminescent pigments react to washing powders and fluorescent optical whiteners in them. Measured sample banknotes are listed in Table 1.

Table 1. Euro Banknotes Used in the Measurements with Information About the Luminescent Pigments Used.

Euro Banknote	Fluorescent Colors Used	Approximate Emission Wavelength
5 Euro banknote	Fl. Orange, Fl. Green (+OVD), Fl. Fibers	614 nm, 515 nm
10 Euro banknote	Fl. Orange, Fl. Green, Fl. Yellow, Fl. Fibers	614 nm, 515 nm, 550 nm
20 Euro banknote	Fl. Orange, Fl. Green (+OVD), Fl. Fibers	614 nm, 515 nm
50 Euro banknote	Fl. Orange, Fl. Green, Fl. Fibers	614 nm, 515 nm
100 Euro banknote	Fl. Orange, Fl. Green, Fl. Fibers	614 nm, 515 nm
200 Euro banknote	Fl. Orange, Fl. Green, Fl. Fibers	614 nm, 515 nm
500 Euro banknote 500 Euro banknote (continued)	Fl. Orange, Fl. Green, Fl. Yellow, Fl. Blue, Fl. Fibers	614 nm, 515 nm, 550 nm
Colors used in luminescent fibers.	Fl. Orange, Fl. Green, Fl. Blue	619 nm, 502 nm, 430 nm,

The light source used in this study was 9 Watt ultraviolet light source which is widely used to detect luminescence in banknotes (excitation wavelength = 365 nm). Optimal excitation wavelength for the luminescent pigments is from 254 nm to 365 nm. A Photo Research Spectra Scan PR-705 spectroradiometer was used to record the radiance spectra and 45/0 measurement geometry was used.

Results

In this study 5, 10, 20, 50, 100, 200 and 500 Euro banknotes were measured. Figure 1 shows the typical Euro banknote pigments' radiance spectra

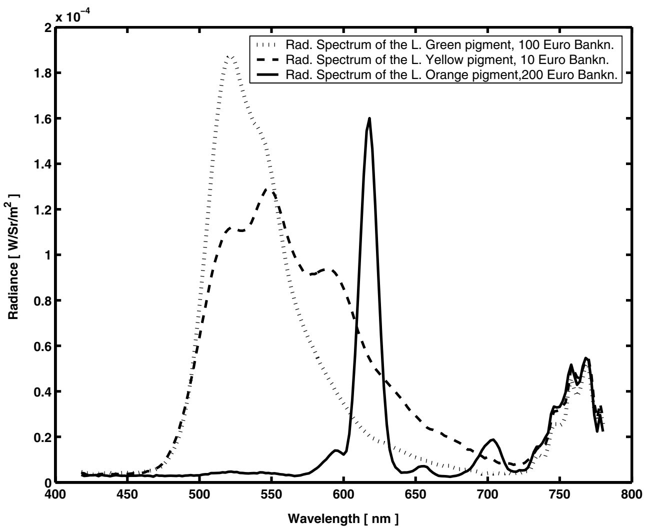

Figure 1. Euro banknote pigments' radiance spectra.

Usually these pigments' luminescent colors (emission wavelength) are fluorescenct green (515 nm), fluorescent yellow (550 nm) and fluorescenct orange (614 nm). These pigments are mainly used in fluorescent printing in Euro banknote's fluorescent offset images and are used with OVD's to create even more complex security patterns.

Figure 2 shows the typical Euro banknote fiber pigments' radiance spectra. These fiber pigments' colors are fluorescent blue (430 nm), fluorescent green (502 nm) and fluorescent orange (619 nm). When we compare Euro banknote's normal luminescent pigments and luminescent fiber's pigments we notice, that fiber's pigments emit stronger fluorescence than the normal luminescent pigments. Usually when these two luminescent security features overlap in Euro banknotes, we can detect this contrast difference also visually.

Figure 3 shows Euro banknote's fluorescent pigment colors' plotted in CIE 1931 chromaticity diagram. Marked areas are the approximate areas for Euro banknote pigments.

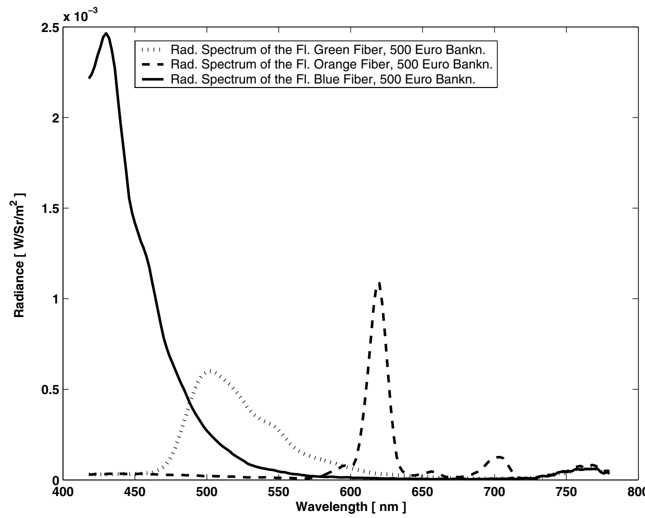

Figure 2. Euro banknote fiber pigments' radiance spectra.

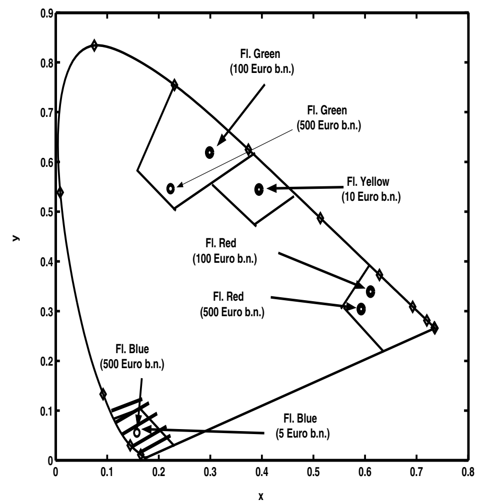

Figure 3. The CIE 1931 x,y diagram, luminescent colors used in Euro banknotes plotted. Approximate areas of used luminescent colors are marked around the measured example colors .

Marked areas match the organic and inorganic substances described in the available literature.[1]

A stress test was performed to define how banknote's luminescent pigments react to the washing powders and the fluorescent optical whiteners in them. Banknotes were washed with the usual white laundry with 3 different kinds of washing powders which included fluorescent whitening agents. After washing each 10 or 20 Euro banknote (one type of banknote per one type of washing powder) we measured the fluorescent pigments radiance (emission) spectra. The banknotes pigments' radiance spectra change so, that there is a strong fluorescence peak in the blue region of the spectrum (around 450 nm). This region is also marked to the Figure 3 by using the dense lines.

Conclusion

Fluorescence pigments are widely used in banknotes, especially with the new currency, Euro, the utilization of luminescent pigments has increased. Fluorescent pigments belong mainly to the second-line authentification group (in this group the authentification is done by shopkeepers by using the ultraviolet light sources). The fluorescence alone does not offer a high level security. But when fluorescence pigments are added to other security devices, the counterfeiting becomes more difficult. Some of things to improve fluorescence in security include: the use of pigments with quite narrow excitation or emission wavelength, using pigments with good light fastness and chemical resistance characteristics, combine different colors to each other to create a new color or combine colors in a way that hidden peaks can be seen only on a spectrophotometer. One should remember, in addition, that when using the fluorescent pigments, the printed images should be complex enough.

When a person accidentally washes his/her banknotes with the laundry, this also disturbs the actual fluorescence in pigments. This effect is quite remarkable. One solution to reduce this whitening agents' effect is to use durable pigments and highly fluorescent colors.

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Biography

Jarkko Mutanen received his MSc. degree in Physics from the University of Joensuu in 1999. Currently he is a post graduate student. His research interests include general color research, fluorescent colors and thermochromism. He is a member of the Finnish Optical Society (FOS).