Luminescent Behavior of American and Canadian Banknotes

Bc. Ondrej Halaska

Master's thesis
2016

Tomas Bata University in Zlín
Faculty of Applied Informatics

Univerzita Tomáše Bati ve Zlíně
Fakulta aplikované informatiky
akademický rok: 2015/2016

ZADÁNÍ DIPLOMOVÉ PRÁCE
(PROJEKTU, UMĚLECKÉHO DÍLA, UMĚLECKÉHO VÝKONU)

Jméno a příjmení:	**Bc. Ondřej Halaška**
Osobní číslo:	**A14425**
Studijní program:	**N3902 Inženýrská informatika**
Studijní obor:	**Bezpečnostní technologie, systémy a management**
Forma studia:	**prezenční**
Téma práce:	**Luminiscence jako součást ochranných prvků bankovek USA a Kanady**
Téma anglicky:	**The Luminescent Behaviour of American and Canadian Banknotes**

Zásady pro vypracování:

1. **Pojednejte o způsobech ochrany bankovek.**
2. **Popište historii amerického a kanadského dolaru.**
3. **Rozeberte použití ochranných prvků bankovek na bázi luminiscence.**
4. **Navrhněte experimentální ověření ochranných luminiscenčních prvků v našich laboratořích.**
5. **Výsledky experimentů a měření zpracujte a vyhodnoťte.**
6. **Navrhněte možnosti dalšího výzkumu na FAI UTB ve Zlíně.**

Rozsah diplomové práce:

Rozsah příloh:

Forma zpracování diplomové práce: **tištěná/elektronická**

Seznam odborné literatury:

1. **TRUKHACHEV, B a M. B. SERGEYEV. Technologies for protection of banknotes and securities, St. Peterburg 2012, 110 p. ISBN 978-5-8088-0780-8.**
2. **PELANT, Ivan a Jan VALENTA. Luminescence spectroscopy of semiconductors. 1st pub. New York: Oxford University Press, 2012, xiv, 542 s. ISBN 978-0-19-958833-6.**
3. **CHIA, Thomas a Michael LEVENE. Detection of counterfeit U.S. paper money using intrinsic fluorescence lifetime. Portal.k.utb [online]. Optics Express, 2009, č. 24. ISSN:1094-4087.**
4. **POWELL, James. A History of the Canadian Dollar. Ottawa: Bank of Canada, 2005. ISBN 0-660-19571-2.**
5. **SIEGEL, Jay A a Pekka SAUKKO (eds.). Encyclopedia of forensic sciences. 2nd ed. Amsterdam: Elsevier, 2013, xliii, 412 s. ISBN 978-0-12-398365-7.**
6. **HAWKES, P a John C SPENCE. Science of microscopy. 1. New York: Springer, 2007, 2 v. (xviii, 1265, I26 p.). ISBN 03-872-5296-7.**

Vedoucí diplomové práce: **doc. RNDr. Vojtěch Křesálek, CSc.**
Ústav elektroniky a měření

Datum zadání diplomové práce: **5. února 2016**

Termín odevzdání diplomové práce: **16. května 2016**

Ve Zlíně dne 5. února 2016

L.S.

UNIVERZITA TOMÁŠE BATI VE ZLÍNĚ
Fakulta aplikované informatiky

doc. Mgr. Milan Adámek, Ph.D.
děkan

doc. RNDr. Vojtěch Křesálek, CSc.
ředitel ústavu

I hereby declare that:

- I understand that by submitting my Diploma thesis, I agree to the publication of my work according to Law No. 111/1998, Coll., On Universities and on changes and amendments to other acts (e.g. the Universities Act), as amended by subsequent legislation, without regard to the results of the defence of the thesis.
- I understand that my Diploma Thesis will be stored electronically in the university information system and be made available for on-site inspection, and that a copy of the Diploma/Thesis will be stored in the Reference Library of the Faculty of Applied Informatics, Tomas Bata University in Zlin, and that a copy shall be deposited with my Supervisor.
- I am aware of the fact that my Diploma Thesis is fully covered by Act No. 121/2000 Coll. On Copyright, and Rights Related to Copyright, as amended by some other laws (e.g. the Copyright Act), as amended by subsequent legislation; and especially, by §35, Para. 3.
- I understand that, according to §60, Para. 1 of the Copyright Act, TBU in Zlin has the right to conclude licensing agreements relating to the use of scholastic work within the full extent of §12, Para. 4, of the Copyright Act.
- I understand that, according to §60, Para. 2, and Para. 3, of the Copyright Act, I may use my work - Diploma Thesis, or grant a license for its use, only if permitted by the licensing agreement concluded between myself and Tomas Bata University in Zlin with a view to the fact that Tomas Bata University in Zlín must be compensated for any reasonable contribution to covering such expenses/costs as invested by them in the creation of the thesis (up until the full actual amount) shall also be a subject of this licensing agreement.
- I understand that, should the elaboration of the Diploma Thesis include the use of software provided by Tomas Bata University in Zlin or other such entities strictly for study and research purposes (i.e. only for non-commercial use), the results of my Diploma Thesis cannot be used for commercial purposes.
- I understand that, if the output of my Diploma Thesis is any software product(s), this/these shall equally be considered as part of the thesis, as well as any source codes, or files from which the project is composed. Not submitting any part of this/these component(s) may be a reason for the non-defence of my thesis.

I herewith declare that:

- I have worked on my thesis alone and duly cited any literature I have used. In the case of the publication of the results of my thesis, I shall be listed as co-author.
- That the submitted version of the thesis and its electronic version uploaded to IS/STAG are both identical.

In Zlin; dated: 13.5.2016

Student´s Signature

ABSTRAKT

Diplomová práce se primárně zabývá americkými a kanadskými bankovkami, respektive jejich ochrannými prvky zahrnujícími luminiscenční jev. Každá nominální hodnota je nejprve podrobena analýze v ultrafialové oblasti elektromagnetického spektra a následně jsou zjištěna místa, respektive ochranné prvky vykazující luminiscenci, které jsou poté analyzovány na spektrofluorometrickém přístroji. Práce také obsahuje souhrn klíčových ochranných prvků zmiňovaných bankovek pořízených pod stereomikroskopem.

Navíc práce popisuje všeobecnou historii platidel, historii jejich padělání a všeobecné informace týkající se bankovek, respektive substrátu, ze kterého jsou vyrobeny, metody jejich tisku a všech možných ochranných prvků.

Klíčová slova: americký dolar, kanadský dolar, ochranné prvky, luminiscence, spektroskopie

ABSTRACT

Master's thesis is primary focused on American and Canadian banknotes, with special respect to their security features which evince luminescence. Firstly, every denomination is examined in the ultraviolet electromagnetic spectrum and then places, especially luminescent security features are detected and examined on the spectrofluorometer. Thesis includes general summary of key security features of mentioned banknotes which were recorded by stereomicroscope as well.

In addition, thesis describes general money history, history of counterfeiting and general information concerning of banknotes, especially the substrate of banknotes, printing processes and all security features.

Keywords: American dollar, Canadian dollar, security features, luminescence, spectroscopy

ACKNOWLEDGEMENTS

I would like to thank you to my supervisor, doc. RNDr. Vojtěch Křesálek, CSc. for precious impulses, advices, comments and ideas during creating of Master's thesis as well as for helpfulness and willingness.

Especially I would like to thank you to all family members, friends and girlfriend who were supporting me during the whole study and in creating of Master's thesis.

CONTENTS

INTRODUCTION

The American dollar is the most used currency in the world. It occupies approximately 43% of the worldwide currency. It dates back to the 17th century. U.S. dollar gradually has come through several changes. It has been several times redesigned, has come several devaluation during its history but it is still alive and worldwide spread. U.S. dollar is accepted almost everywhere.

The Canadian dollar occupied approximately 2% of the worldwide currency. It dates back to the 17th century as well but Canadian dollar is a little bit older than American dollar. Canadian currency gradually has come through several changes as well as American currency. Canadian currency is valid only in Canada and its territories. Since 2011 all paper-cotton banknotes have been replaced by polymer banknotes but paper-cotton banknotes may still appear in the circulation.

Master's thesis describes general money history, history of counterfeiting and general information about banknotes. There are described kinds of banknotes and their advantages and disadvantages. Deeper description is concerning to general security features of all banknotes. Much deeper description is concerning of American and Canadian dollar which is focused on their history, history of counterfeiting and mainly to the security features but to the lifecycle as well. There is also described the term luminescence and luminescence spectroscopy that is related with this thesis.

Practical part of thesis is focused to the real outputs. There is the detailed analysis of American and Canadian dollar. Analysis includes photos of mentioned currency on daylight, when passing daylight, under UV lamp – to detect if banknotes evince luminescence or do not, photos taken shot under stereomicroscope for detailed detection of security features and banknotes substrate. Finally, there is the spectrofluorometer analysis that is focused on the luminescence of banknotes, especially security features and their substrates.

Thesis contains possible additional utilization how to distinguish genuine and counterfeited banknotes based on final outputs.

I. THEORY

1 GENERAL MONEY HISTORY

History is as old as humanity itself. The first sources of human history come from cave-men, especially from their painters from caves. History is very important for us, because we should have knowledge about ourselves. That is it to write some facts about money history.

Since people have started to have their own property, first economic situation has occurred, where someone has had something and someone has had something else. And therefore a first business has been created. The first time there has been the exchange business – goods have been exchanged for other goods. This kind of business has been also known as barter. Afterwards goods have been exchanging for valuable goods, such as Slavic scarves, sea shells (north and seaside tribes) but it has mostly been gold, silver, semi-precious stones and precious stones. [1]

A real money has been occurred around 3 500 B.C. in Mesopotamia. Money has been used as a currency and something what keeps its value. Some historians even think, that the first font has been created because of money has had to be recorded, such as been transactions and bank accounts. [1]

Fig. 1: The first coin (Lydian coin) [1]

Some sources present, that the first banknotes – called "states banknotes" has been released at the turn of the 2nd and 1st century B.C. in China. They have been made from white deer leather and written by brush. [2]

Other sources present, that the first printed "state banknotes" have been also made in China. In 807, the Chinese emperor Hian-chong commanded to withdraw all gold and silver coins into the state treasury and he released certificates for them, which were accepted as an ordinary coins. Certificates already contained security features – fine ornaments. For those, who wanted to counterfeit certificates, there was a death penalty and on the other hand a reward to informer. It could be said that state banknotes are older than present banknotes. [2]

Another source present, that approximately in the 9th century A.D. has been released first banknotes in China. It was a response for a shortage of copper, from which coins were minted. [3]

The first banknotes in Europe were discovered in 1171 in Venice. It was not banknotes as are known nowadays. It was hand-written receipts for people, who kept their coins at the businessmen. State took over this kind of receipts system and started to use as official currency in the beginning of 11th century. [2]

Fig. 2: The oldest known banknote [4]

2 GENERAL HISTORY OF MONEY COUNTERFEITING

History of money counterfeiting is as old as money has been invented. People have tried to counterfeit currency from its beginning because of aversion to work, poverty, etc. To counterfeit money have looked like a good opportunity to earn a lot of money for a little effort.

History of money counterfeiting is as old as money itself. We know from extant historic sources, that money counterfeiting already comes under into Antic period. Already, in the 5th century, when emperor Justinian was reigning, there was a man called Alexander Barber, who had a great talent for money counterfeiting, that the emperor employed him in government, especially in financial department. [5]

Coins have been made from valuable metals, such as gold or silver. Among the first methods of counterfeiting coins have been mixing of different metals into pure gold or silver. Afterwards, people have invented more sophisticated methods, where a counterfeited coin from non-noble metal has been covered by valuable metal, especially by gold or silver. Counterfeited coins have not been recognized because of this method at first sight. The lead has been used as a base of a coin. As the time has been going, counterfeiters have come across a problem – counterfeited coins have not been smooth and shiny because of a chemical reaction between lead and valuable metal (gold or silver). Counterfeiters have been invented a new method because of the previous method has not been too successful. A new method has been called “three-layer”. Between lead and gold or silver layer a copper layer has been located (copper layer). This copper layer has been caused, that a counterfeited coin looks more like genuine coin. Period counterfeiters have had a deep knowledge about chemistry because of the first counterfeits have been de facto chemical reactions between two or more metals. [6]

Banknotes became a legal currency in USA at the turn of the 17th and 18th century. Marry Butterworth has been one of the first counterfeiters. She has transformed a pattern of banknote on a paper by starching of fabric and hot iron and she has created a design of a banknote by staining with quill. [5]

3 GENERAL OVEVIEW ABOUT BANKNOTES

Banknotes are not printed on an ordinary paper as is known from common life. If it would be so, banknotes would not be resistant against its life cycle and would be easier to counterfeit them. Technologies of processes of banknotes printing are relatively difficult, may be said they need specialized machines, materials and knowledge for print them out.

3.1 What Are Banknotes Made From

Banknotes may be divided into three categories:

- Paper.
- Polymer.
- Hybrid.

3.1.1 Paper Banknotes

The base of paper banknotes is not an ordinary paper but specialized/ security paper. Generally may be said, that it is a mix of different materials.

Paper is leaf-fibrous material, which is made by paper-producing machines. It is composed from vegetative fibers, which are mostly made from wooden cellulose with additives of cotton, flaxen and other-related fibers. Process of paper production is composed from phases as follows:

- Pulping and bleaching of cellulose.
- Pulverize and preparation of paper material.
- Casting of paper strip by paper-producing machine.
- Scanning, monitoring and cutting of paper. [7]

Initial material (wooden pieces) is cleaning, cooking and bleaching in the first phase of process. Next step is milling and grinding within water tank until homogeneous material is made. Cotton and flaxen fibers, or some additional materials, are added into homogeneous material, which provides strength and durability to the paper. Nowadays is more common to add extra synthetic fibers into initial material, which provides stronger and more durable banknotes. Besides synthetic fibers, binders, fillers (chalk), dyes and bleaching materials are added into paper material to provide required parameters as follows:

- Necessary strength.
- Density.
- Adhesion of colors.
- Whiteness.
- Required colored shade.
- Optical density (absorbance).
- Decrease of basic level of luminescence paper background when illuminated by UV light. [7]

Structure of paper material can also contain various kinds of security fibers – vegetative or synthetic; colored and colorless, impregnated by luminophores (a material, where luminescence occurs) or without luminophores, two-colored with variable cross-section as well as metal fibers with magnetic features. [7]

Fig. 3: Security fiber within paper structure [7]

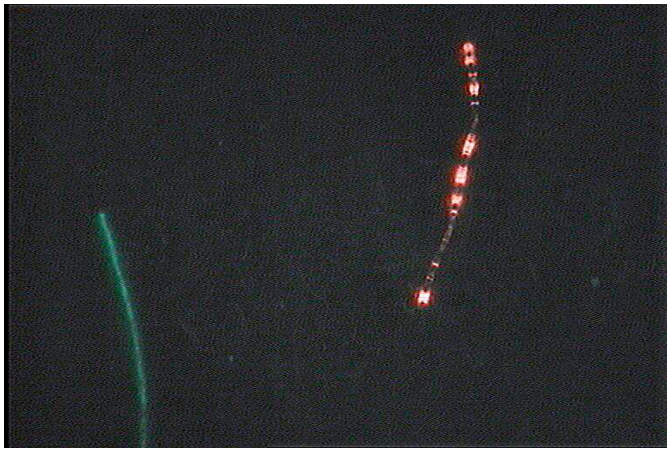


Fig. 4: Luminescence of security fiber [7]

3.1.2 Polymer Banknotes

First polymer banknotes were introduced in 1988. They have several advantages than paper banknotes:

- Durable – up to 5 times longer life cycle – it means less production of banknotes.
- Waterproof – resistant against any kind of water (fresh, salt water) and washing machine.
- Secure – allows higher security than paper banknotes.
- Clean and Green – contain less bacteria and they are more environmental friendly than paper banknotes. [8]

Polymer banknotes are made from polymer substrate on which to print the normal offset and intaglio print layers. 99% of polymer banknotes are made by Innovia Security that is supplier of Guardian® substrate. [8]

Guardian substrate is consisted of the three major elements:

- The base film (Clarity®C).
- The opacified print layers - enable offset and intaglio inks to adhere to the substrate.
- Security features – either printed or embedded into substrate.

Polymer substrate is created by using a unique "bubble" process, in which a four storey-high chamber, gravity and air are used to creation the base film called bi-axially oriented polypropylene (BOPP) that is use only for Guardian® substrate creation. The base film is combined with opacification print layers and security features that are both embedded and printed into substrate. Clarity®C is a unique film that can be immediately identified and authenticated. [8]

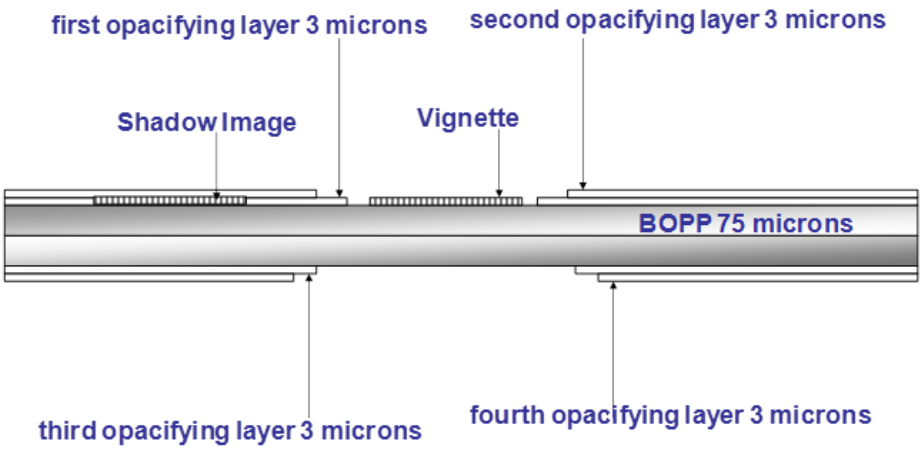


Fig. 5: Structure of Guardin substrate [8]

3.1.3 Hybrid Banknotes

Hybrid banknotes are combination of traditional paper banknotes with polymer banknotes. The first hybrid substrate was introduced in 2008 by G&D Company. [9]

Hybrid substrate is a combination of cotton fibers with a protective film layer on each side. The protective polyester film layers provide excellent protection against soil water and tearing. Within the cotton fibers are integrated security features, such as watermarks, security threads and fluorescent fibers that allows reliable authentication of banknotes. An innovative ink primer ensures optimum printing characteristics on each side of the banknote. Hybrid substrate has the same printing properties as ordinary banknote paper. It is mostly suitable to countries that have diverse climate zones and demanding circulation conditions. [9]

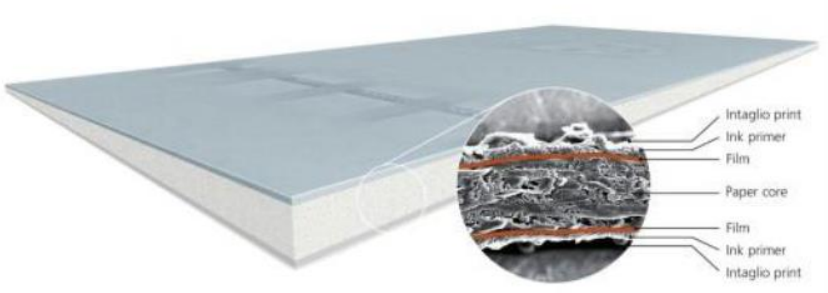


Fig. 6: Hybrid substrate composition [9]

Hybrid substrate is a good solution for banknote manufacturing. As it mentioned before, it is a combination of cotton fibers (paper banknotes) with polymer substrate (polymer banknotes) that allows several outstanding features as follows:

- Lower production cost than polymer banknotes production.
- More durable than paper banknotes.
- Remains clean and stiff in extreme conditions.
- Outstanding embedded and printed security features.
- Waterproof. [9]

3.2 Printing of Banknotes

There are three types of banknote printing. It is commonly used any combination of these three printing process. Screen printing may be also used for printing of specialized features.

3.2.1 Intaglio

This kind of printing has been used for engravers artworks, invitations, and banknotes. The image that was to be made was engraved by hand of artist into a metal plate (lines and dots were engraved of varying length and depth). A viscous and opaque ink is applied into the engravings, while the rest of the plate surface is clean. Image in transferred onto substrate by high pressure. [10]

Intaglio is appropriate printing process for security documents such as banknotes because of its unique characteristics (raised and embossed texture). It is very difficult to achieve these characteristics that provide intaglio printing by other printing methods. Another unique characteristics of this kind of printing is the “feathering”, it produces along the edges of printed area. These features of ink spread along paper fibers, along the tonal qualities that are capable of producing. Nowadays are commonly used a computer-assisted laser devices to engrave the intaglio plates. [10]

Fig. 7: Front side of banknote – wide range of color tones [11]

Fig. 8: Reverse side of banknote – paper deformation [11]

3.2.2 Letterpress

During this kind of printing process, ink is applied to a raised surface which is then transferred to the substrate by direct impression. One of the characteristics of letterpress is a slight indentation of embossing of the paper from the impression. Another characteristic is the slightly darker and thicker outline of letterpress image area due to the excess ink being squeezed toward the edge. This kind of printing is commonly used to add unique identifying features to banknotes such as serial number. [10]

Fig. 9: Front side of the print [11]

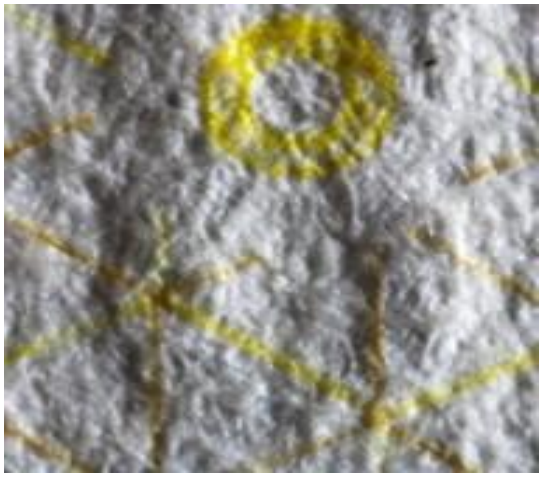


Fig. 10: Reverse side of the print [11]

3.2.3 Offset

Offset lithography is a flat printing process that does not have any typical characteristics, which can be found in intaglio or letterpress. This kind of printing is commonly used in commercial industry for printing high-volume items such as newspapers. Wet offset creates images on a flat, metal, printing plate for single printing. Chemical differences between the image and area without image allow for the image areas to accept ink and areas without image to resist ink. Unlike most traditional printing process, such as intaglio and letterpress, where the printing place comes into direct contact with the substrate, offset lithography is an indirect printing process. First, the ink is transferred from the printing plate to a transfer plate or "blanket" and to the desired substrate. [10]

The main characteristic of offset printing is that an area with image appears sharp and even with very crisp lines and edges. There will not be any "feathering" as can be found with intaglio or a dark outlines due to ink build up as can be found with letterpress. Because offset is an indirect printing, there will not be any embossing of the substrate from contact with the printing plate. [10]

While offset printing is used in commercial industry for a variety of items, it allows for additional layer of security in the printing of documents and banknotes. More advanced offset presses are capable of exceptionally tight registration between images on the front and back of the documents as well as the ability to print very fine interwoven lines of varying color saturation. This creates images with qualities that are extremely difficult for counterfeits to reproduce whether using traditional or digital methods. [10]

Dry offset lithography is another form of offset printing that used a raised image area but still uses the transfer "blanket". Images created this way maybe have some of the same characteristics of letterpress but the substrate will not demonstrate any signs of embossing. [10]

Fig. 11: General viewof offset [11]

Fig. 12: Zoomed fragment of offset [11]

3.2.4 Screen Printing

This kind of printing process uses a stencil and screen to create images. Ink is forced through the screen onto the substrate. The ink used is extremely thick in a slightly raised image. But on the other hand, the patterns of the screen can sometimes be seen along the edges of images created with this process and because no considerable pressure is applied, the substrate will not be demonstrate any embossing. Screen printing is used to apply specialized optically variables security features to banknotes. [10, 11]

Fig. 13: General view of screen printing [7]

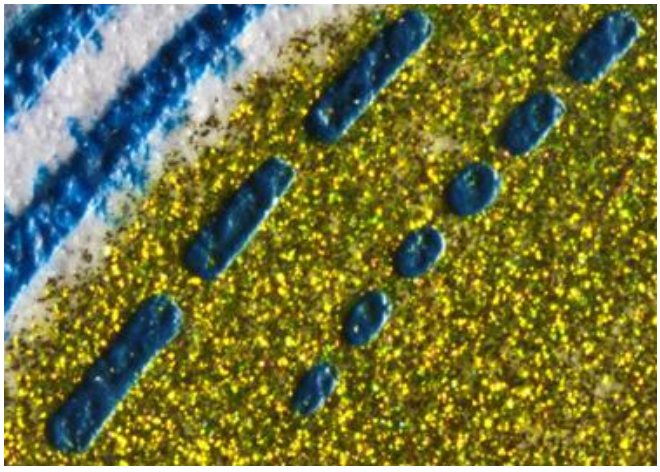


Fig. 14: Fragment of screen printing [11]

3.3 Security Features

Every valuable, such as documents, securities and banknotes contain a large range of security features against potential counterfeiting. Security features can be divided into two groups:

- Security features that can be detected by eye.
- Security features that can be detected by appropriate equipment, such as UV/IR detectors, automatic detectors and others. [12]

Most of security features, such as watermark, security fibers, magnetic strip, iridescent strip, micro text, hidden pattern, etc., are detected by eye. But on the other hand some of

them, such as microtext or hidden pattern cannot be eye- detected well because of their little, even small structure. So it is better to use magnifying glass or microscope.

Luminescent dyes, features detected UV or IR light, hidden patterns are detected only with appropriate equipment.

3.3.1 Paper

Paper is a basis of most banknotes in the world, such as U.S. dollar, euro, rubble, etc. But on the other hand there are polymer and hybrid banknotes that are described in previous chapter. [7, 11]

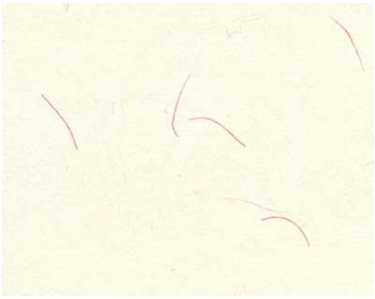


Fig. 15: Paper [13]

3.3.2 Watermark

Watermark is the oldest and very reliable security feature of banknotes and documents. Watermark is produced during a paper production, where it is applied on the paper by special tool called an eguter. The eguter is light cylinder from mesh, where an ornament is installed, which extrudes watermark (an ornament) on the wet paper. Watermark is introduced during paper moisturizing, and therefore it called watermark. [7, 13, 14]

Watermark is clear when banknote is viewed against the light. It is used a combination of dark and negative watermark. This means, if you look on a banknote, especially on the watermark against the light, you will see different shade – light and dark. There are three types of watermark:

- Single-tone.
- Two-tone.
- Multi-tone (also known as cylinder mould watermark). [7, 13, 14]

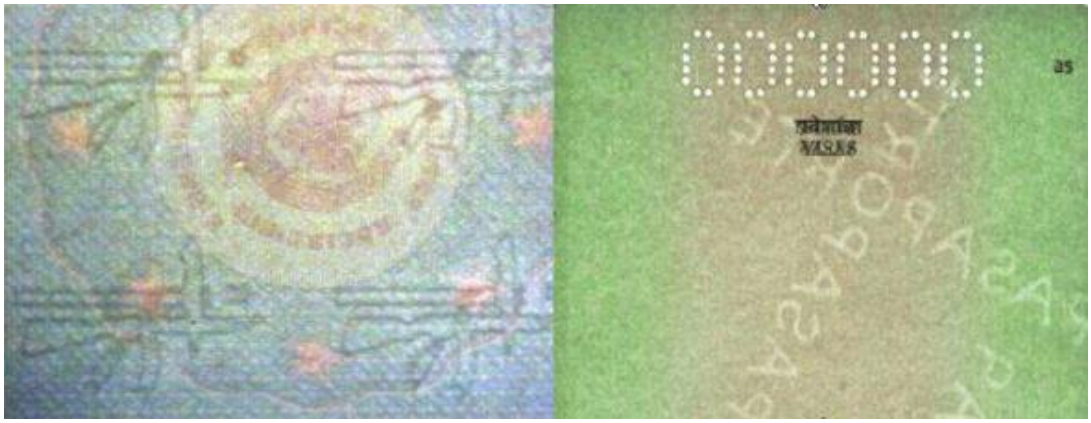


Fig. 16: Single-tone dark (on the left) and light (on the right) watermark [13]

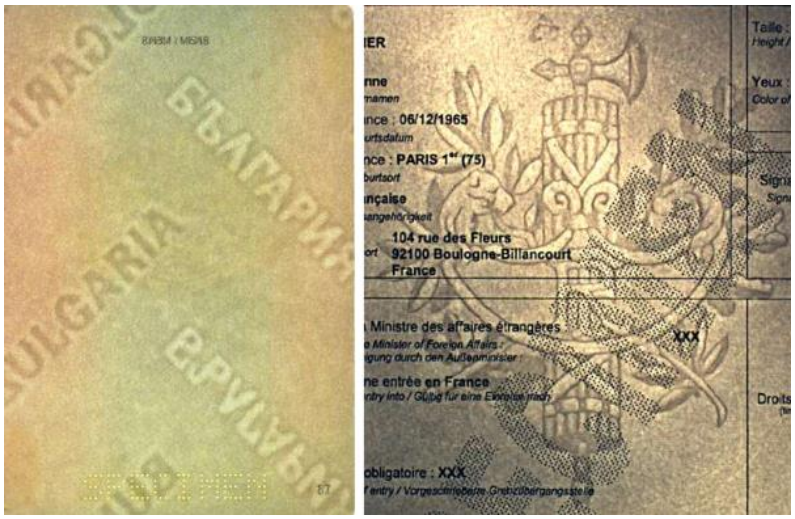


Fig. 17: Two-tone light and dark watermark [13]

Fig. 18: Multi-tone watermark [13]

3.3.3 Security Thread

Security threads are elements that are embedded into paper during papermaking process. They provide high security against counterfeiting thanks to the complex techniques. Security threads offer a wide range of application because of their design. They can be as a holographic or color-shifting, and contain multi-functional characteristic such as holograms, demetallization, UV luminescence and machine readability. [15]

Fig. 19: Security threads (color-shifting, holograms, demetallization) [15]

3.3.4 Security Fiber

Security fibers are embedded into paper during papermaking process. Some of them can contain luminophores that emit radiation when illuminated by UV light. They are randomly placed. [12]

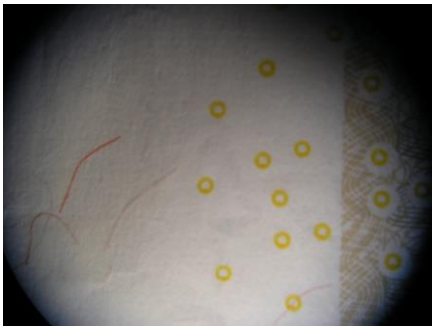


Fig. 20: Security fibers

3.3.5 Security Ribbon

Security ribbon is woven into paper during papermaking process, not printed on it. It contains microtext or various ornaments and can be emitted when illuminated by UV light. When banknote is tilted back and forth, ornaments on the ribbon can move. [16]

Fig. 21: Security Ribbon [16]

3.3.6 Hidden Feature

Hidden feature – an image is viewed only when banknote is tilted. Images can be colored or each item of image can contain its own color. They are viewed also under UV light where each item of image can contain a unique color as well. [11]

Fig. 22: *500 Russian Ruble view at right angle [11]*

Fig. 23: 500 Russian Ruble

view when tilt [11]

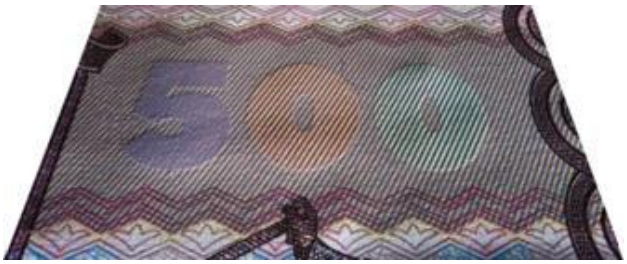


Fig. 24: 500 Russian Ruble view when tilt and

rotate [11]

3.3.7 EURion Constellation

Also known as Omron rings, is a pattern of symbols, especially rings of the same dimension. They are printed by offset. Omron rings are used against copying. [11]

Fig. 25: Omron rings on 500€ [11]

3.3.8 OVI (Optical Variable Ink)

A special ink based on optically variable pigments. The pigment changes its color according on the angle of light incidence and view. The ink is applied by intaglio or screen printing. It is important for colors to be contrasting and well distinguishable in this case. [11]

Fig. 26: OVI of 500€ (view at right angle, view at an acute angle) [11]

3.3.9 Iridescent Ink

A semi-transparent ink contains a nacreous glitter (Figure 27). Iridescent ink contains transparent pigments consisting of tiny mica scales covered with a thin film (Figure 28). These pigments generate interference of incident light and produce the color changing effect, when changing the angle of view or entrance. The iridescent element is not seen at right angles. [11]

Fig. 27: Iridescent ink – view under oblique light [11]

Fig. 28: Iridescent ink – zoomed area of the image [11]

3.3.10 Microprinting

Microprinting is printed by intaglio or offset. It usually contains repeated words, number or text 0.15-0.3 mm high. Microprinting is clearly visible only with appropriate devices such as magnifying glasses or microscopes. There are three types of microprinting:

- Positive – contains dark letters on a light background (Figure 29).
- Negative – contains light letters on a dark background (Figure 30).
- Reversed (turned out) – changes gradually from negative to positive and vise versa (Figure 31). [11]

Fig. 29: Positive microprinting [11]

Fig. 30: Negative microprinting [11]

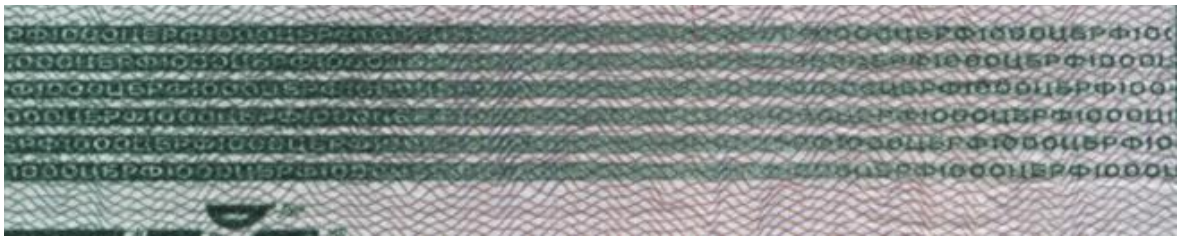


Fig. 31: Reversed microprinting [11]

3.3.11 Luminescent Printing

Luminescent ink contains fluorescent substances (pigments) that emit when illuminated by UV light. Fluorescent substances are not visible under normal daylight, only under UV light. The same substance (pigment) may have different sensitivity to UV radiation of different wavelengths. Luminescent ink may be used for printing for certain graphic items and general items of the banknotes as well. [11]

Fig. 32: Banknote under daylight and UV light

3.3.12 Infrared Printing

Infrared printing is similar to luminescent printing. It contains fluorescent substances (pigments) that emit when illuminated by IR light. It may be colored or colorless. The substances are not visible under daylight. They can be detected by appropriate devices (IR detectors). [11]

Fig. 33: Infrared printing on Serbian Dinar [11]

3.3.13 Numbering

It is a unique combination of letters and (or) numbers that are assigned to each banknote. Serial numbers are usually printed by letterpress. They may contain luminescent or infrared ink, or magnetic ink. Serial numbers provide information about a year of issue and series, an issuing bank, a factory, a face of value, etc. [11]

Fig. 34: Multicolored serial number [11]

3.3.14 Planchet

Planchettes are thin round or polyhedral pieces (1-4 mm) that are made from polymer or paper. They are embedded into paper during papermaking process or pressed to its surface layer. Planchettes are randomly placed or as a strip in a certain place of the banknote. They can be colored and contain luminophores. Moreover they provide security against copying banknotes by copiers (planchettes have high reflection power). [11]

Fig. 35: Round planchettes [11]

Fig. 36: Hexahedron planchettes with iridescent coating [11

3.3.15 Kinegram/ Hologram

Patterns manufactured from foil that are pressed or sticked on the banknote paper, documents or other securities during final manufacturing process. They contain an image burnt by laser out. Kinegrams (holograms) are diffractive optically variable devices. The holographic image is created by diffraction and refraction of light and changes at different angles during observation. [11]

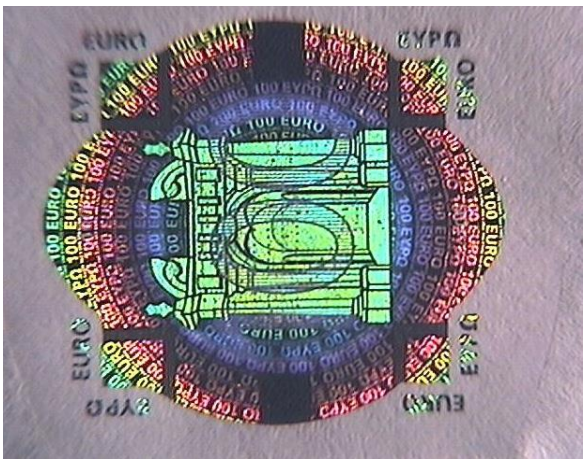


Fig. 37: Kinegram with holographic effect on 100€ [7]

3.3.16 Microperforation

Microperforation is used on banknotes, documents and securities. It is consisted from micro holes (less than 30 micrometer) made by laser and forming an image, which is seen in transmitted light. [7, 11]

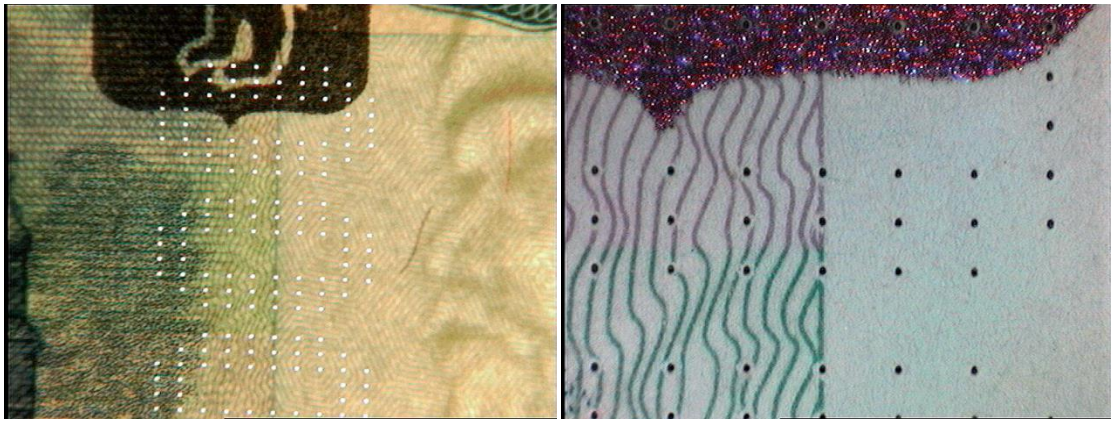


Fig. 38: View when transmitted/ reflected light [11]

3.3.17 Magnetic Ink

Magnetic ink contains ferromagnetic components that provide a specific reaction to the external magnetic field. The components may be added to the ink of any color or colorless item (varnish) of banknote. The items contain the magnetic ink may be identified by special magnetic sensors or visualized by special devices. [11]

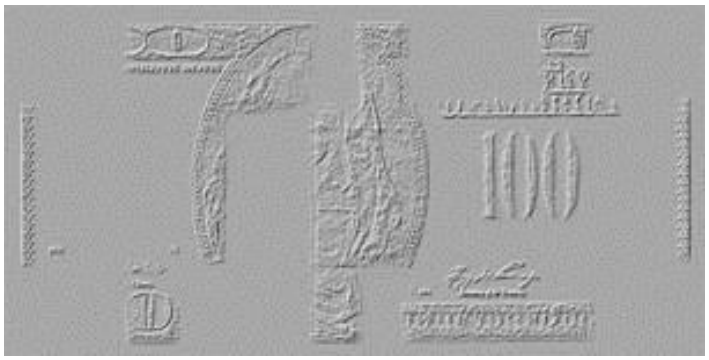


Fig. 39: Ferromagnetic components on $100 [11]

3.3.18 RFID

RFID chips are little tags where information can be stored in electronic way. They contain transmitting/ receiving antenna and charging capacitor. If banknote contains the RFID chip will appear near the reader, which is transmitting electromagnetic pulses in its area, capacitor is charged and communication between RFID chip and reader can begin. Thanks to its dimension can be chips easily installed and hidden. Chips store number of central bank and can be found when they will be stolen. This kind of security is modern but nowadays does not exist any banknote with RFID chip. On the other hand, it is only matter of time when they will be installed. **[**14]

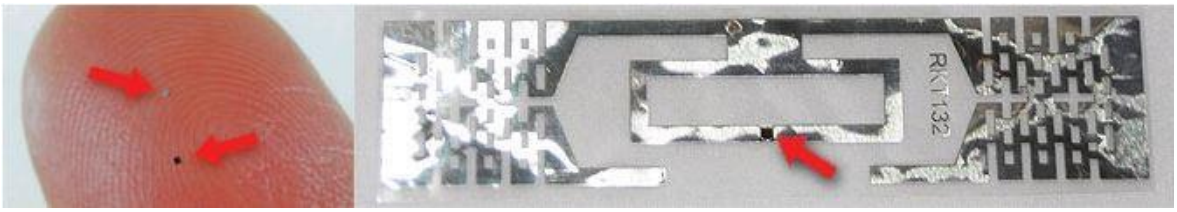


Fig. 40: RFID chip/ RFID with antenna [14]

4 AMERICAN DOLLAR

American dollar is the most used currency in the world, approximately 43%. Next chapters are dedicated to American dollar and deeply described as well.

4.1 History of American Dollar

History of U.S. currency dates back to the 17th century, especially to 1690. This is the year of born of paper currency in the United States. First paper currency was issued by the Massachusetts Bay Colony to fund military expeditions. Other colonies in the United States quickly took up the practice of issuing paper currency. This period of paper notes can be marked as period of Colonial Notes. [16]

In 1739, Benjamin Franklin took on counterfeiting, using his Philadelphia printing company to produce colonial notes with nature prints. There are occurring the first unique patterns focused against counterfeiting. Paper notes contain unique raised patters cast from actual leaves. This period of paper notes can be marked as period of Franklin´s Unique Colonial Notes. [16]

In 1775, the phrase "not worth a Continental" occurred after the Continental Congress issued paper currency to finance the Revolutionary War. Currency quickly lost its value because of a lack of solid backing and the rise of counterfeiting. This period of paper notes can be marked as period of Continental Currency. [16]

In 1776, the first $2 banknotes are Continentals. In this year, Continental Congress authorized issuance of the $2 denomination in "bills of credit" for the defense of America. This period of paper notes can be marked as period of The First $2 Note. [16]

In 1861, there was a need to finance the Civil War, and therefore Congress authorized the U.S. Department of the Treasury to issue non-interest-bearing Demand Notes. These notes were marked as "greenbacks" because of their color. All U.S. currency that was issued since 1861 remained valid and redeemable at full face value. In this year (1861) were issued the first $10 notes (Demand Notes), featuring President Abraham Lincoln's portrait, by the U.S. Department of the Treasury. This period can be marked as period of Demand Notes and The First $10 Notes. [16]

In 1862, Congress authorized a new type of currency, also known as "United States notes", or "Legal Tender notes". These paper notes are characterized by a red seal and serial num-

ber, and continued to circulate until 1971. During 1862, the Demands Notes were equipped by several anti-counterfeiting items, especially fine-line engraving, intricate geometric patterns, a U.S. Department of the Treasury seal, and engraved signatures. This period can be marked as period of the United States Notes and The Foundation of Modern Design. [16]

In 1863, Congress founded a national banking system and authorized the U.S. Department of the Treasury to oversee the issuance of National Banknotes. This system determined Federal guidelines for chartering and regulating "national" banks and authorized those banks to issue U.S. currency secured by the purchase of United States bonds. This period can be marked as period of the National Banking System. [16]

In 1865, the United States Secret Service was founded to deter counterfeiters because counterfeiting diminish the public's confident in the U.S. currency. This period can be marked as the Establishment of the Secret Service. [16]

In 1869, the Bureau of Engraving and Printing was started to engrave and print the faces and seals of U.S paper notes. Previously, U.S paper notes were produced by private banknote companies and then sent to the Bureau of Engraving and Printing for making seals, trimming, and cutting. This period can be marked as The Centralized Printing of United States Notes. [16]

In 1889, U.S legislation mandated that all banknotes and other securities that contain portraits must include the name of the individual below the portrait. This is why we are able to see names below the portraits on banknotes to this day. This period can be marked as Adding Names to Portraits. [16]

In 1913, the Federal Reserve Act of 1913 founded the Federal Reserve as the nation's central bank and provides for a national banking system that is more responsive to the fluctuating financial needs of the all country. The Federal Reserve Board issued new paper currency, which is called Federal Reserve notes. This period can be marked as The Federal Reserve Act. [16]

In 1914, the first $10 Federal Reserve banknotes were issued. The banknotes were larger than today´s banknotes and involved a portrait of President Andrew Jackson on the face. This period can be marked as The First $10 Federal Reserve Notes. [16]

In 1918, Federal Reserve Board started to issue currency in $500, $1,000, $5,000, and $10,000 denominations. This period can be marked as The Introduction of Large Denomination Banknotes. [16]

In 1929, the appearance of U.S. banknotes was greatly changed because of achieving lower manufacturing costs. All Federal Reserve notes (including today's banknotes) are made about 30% smaller (6.14 x 2.61 inches) than previous banknotes (7.38 x 3.13 inches). Also standardization has been done, especially designs were instituted for each denomination, decreasing the number of designs in circulation and making it easier for the public to differentiate genuine and counterfeited banknotes. This period can be marked as Standardization of Design. [16]

In 1957, motto "In God We Trust" is involved on all currency because of salutatory regulation, especially banknotes on series 1957 $1 silver certificates then on 1963 series Federal Reserve notes. This period can be marked as Born of Motto "In God We Trust". [16]

In 1969, all banknotes in denomination of $500, $1,000, $5,000, and $10,000 would be discontinued due to lack of their use. These banknotes were issued until 1969, although last banknotes were printed in 1945. This period can be marked as End of Large Denomination Bills. [16]

In 1971, the issuance of banknotes was discontinued, no new U.S. banknotes were placed into a circulation because no longer served any function not already adequately met by Federal Reserve notes. This period can be marked as United States Notes Discontinued. [16]

In 1976, the $2 banknotes was reintroduced featuring a new vignette: Trumbull's painting, "The Signing of the Declaration of Independence", on the 233rd anniversary of Thomas Jefferson's birth. This period can be marked as Reintroduction of the $2 Note. [16]

In 1990, new security features were introduced, especially a security thread and microprinting, in Federal Reserve notes to prevent counterfeiting by copiers and printers. These new features first appeared in Series 1990 $100 notes, and in Series 1993 on all denominations except $1 and $2 notes. In the same year, The Bureau of Engraving and Printing's Western Currency Facility in Fort Worth, Texas, started to produce currency – the first government facility outside Washington, D.C., to print Federal Reserve notes. This period can be marked as Introducing of Security Thread and Microprinting and Establishment of Western Currency Facility. [16]

In 1996, U.S. currency was redesigned, since 1920s, to incorporate a series of new anti-counterfeit features. Issuance of the new banknote started with the $100 note in 1996, the $50 note in 1997, the $20 note in 1998, and the $10 and $5 notes in 2000. This period can be marked as Currency Redesign. [16]

In 2003, the new design $20 note was introduced. The $20 note contains subtle background colors of green and peach, and an embedded security thread that glows green when illuminated by UV light. When held to light, a portrait watermark of President Jackson is visible from both sides of the banknote. The note contains a color-shifting numeral 20 in the lower right corner of the note. This period can be marked as The Redesigned $20 Note. [16]

In 2004, the new design $50 note was introduced. The $50 note contains subtle background colors of the blue and red, and an embedded security thread that glows yellow when illuminated by UV light. When held to light, a portrait watermark of President Grand is visible from both sides of the banknote. The note contains a color-shifting numeral 50 in the lower right corner of the note. This period can be marked as The Redesigned $50 Note. [16]

In 2006, the new design $10 note was introduced. The $10 note contains subtle background colors of orange, yellow and red as well as an embedded security thread that glows orange when illuminated by UV light. When held to light, a portrait watermark of Alexander Hamilton (Treasury of Secretary) is visible from both sides of the banknote. The note contains a color-shifting numeral 10 in the lower right corner of the note. This period can be marked as The Redesigned $10 Note. [16]

In 2008, the new design $5 note was introduced. The $5 note contains subtle background colors of light purple and gray as well as an embedded security thread that glows blue when illuminated by UV light. The note contains two watermarks that are visible from both sides of the banknote when held to light. A vertical item of three numeral 5s is placed to the left of the portrait and a large numeral 5 is placed in the blank space to the right of the portrait. This period can be marked as The Redesigned $5 Note. [16]

In 2013, the new design $100 note was introduced since 1996. The $100 note contains a 3-D Security Ribbon and color-shifting Bell in the Inkwell, and a portrait watermark of Benjamin Franklin, which is visible from both sides of the banknote when held to light. This period can be marked as The Redesigned $100 Note. [16]

4.2 History of U.S. Currency Counterfeiting

During American Independence period were Congress-Notes in circulation. During this period banknotes were not so properly as secured as today´s banknotes and therefore it was easier to counterfeit them. Because of this, banknotes were equipped by special typefaces and type ornaments, something cut by hand, in the hopes that counterfeiters will not find a way how to counterfeit them. [17, 18]

The golden age of counterfeiting was during the Civil War. In 1862 the United States produced banknotes by the national government legal tender. This expansion meant a revolution in American finance (before that there was not a single currency). The Civil War produced a federal monopoly on paper currency. After single currency implementation, counterfeiters felt the effects immediately – it was not to easily counterfeit currency as before. On the other hand ordinary people had to distinguish between genuine and fake banknote. Therefore, in 1865 the Treasury Department was created to detect and arrest counterfeiters. During the Civil war one third or more of the banknote in circulation were fraudulent. [17, 18]

Marry Butterworth has been one of the first counterfeiters. She has transformed a pattern of banknote on a paper by starching of fabric and hot iron and she has created a design of a banknote by staining with quill. [17, 18]

Probably one of the most famous and most prolific counterfeiters in American history, is Frank Bourassa, who has produced more than $200 million in nearly flawless fake twenties stuffed in a garage (in 2009). Frank has made money from by traditional cotton and linen recipe and watermark image of Andrew Jackson's face. Fake twenties also contained security strips. All his knowledge became from pirates websites, especially from counterfeit's discussion forums and also from paper mills from Europe and Asia, which reached out them under fake name, as an employee of The Letter Shop, a fictitious Canadian company. He has had very sophisticated way how to realize all process, from contacts over the world, to fake bank accounts, presses and final customers (counterfeit money were exported). After several years Frank has been arrested and after several trials and sentences, now he is working as consultant for governments and business in fraud-protection tactics. [19]

4.3 Security Features

Security features are important elements to disable counterfeit banknotes. Each banknote has its specific security features that are described below. Of course $100 banknote has more sophisticated security features than $1 banknote but still it is almost impossible to counterfeit even $1 banknote without appropriate machines and tools.

4.3.1 Federal Reserve Seal

A black seal, which have only $1 and $2 denomination, to the left of the portrait bears the name and corresponding letter of the distributing Federal Reserve Bank. [21]

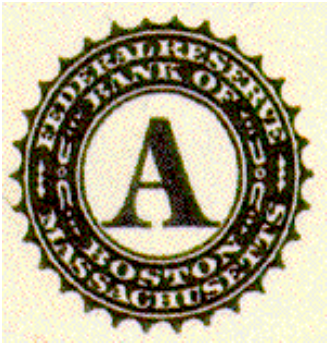


Fig. 41: Federal Reserve Bank Seal [22]

4.3.2 Federal Reserve System Seal

New banknotes from $5 denomination to higher have a black seal to the left of the portrait that represent the entire Federal Reserve System. A letter and number under the left serial number identifies the distributing Federal Reserve Bank. [21]

Fig. 42: Federal Reserve Bank Seal [23]

4.3.3 Treasury Seal

A green seal is situated on the right side of the portrait. It represents the U.S. Department of the Treasury. The design of the treasury seal was changed to incorporate an English inscription and appears on all Federal Reserve banknotes of the 1969 series year or later. [21]

Fig. 43: Treasury Seal [24]

4.3.4 Raised Printing

When you move your finger along the banknote's surface you can feel the raised printing that gives genuine Federal Reserve banknotes their distinctive texture. Raised printing has all U.S. banknotes. [21]

Fig. 44: Raised Printing [25]

4.3.5 Paper

As it mentioned in the previous chapter (Chapter 3.1.1), the Federal Reserve banknotes are made from 75% of cotton and 25% of linen with embedded security red and blue fibers. All U.S. banknotes are made by the same way. [21]

4.3.6 Portrait and Vignette

Each U.S. banknote has its own portrait of famous American character.

The $1 banknote has the portrait of George Washington on the front side and an image of the Great Seal of the United States on the back side. [21]

Fig. 45: $1 front/ back side [26]

The $2 banknote has the portrait of Thomas Jefferson on the front side and a vignette showing the signing of the Declaration of Independence on the back side. [21]

Fig. 46: $2 front/ back side [26]

The $5 banknote has the portrait of President Lincoln on the front side and vignette of the Lincoln Memorial on the back side. [21]

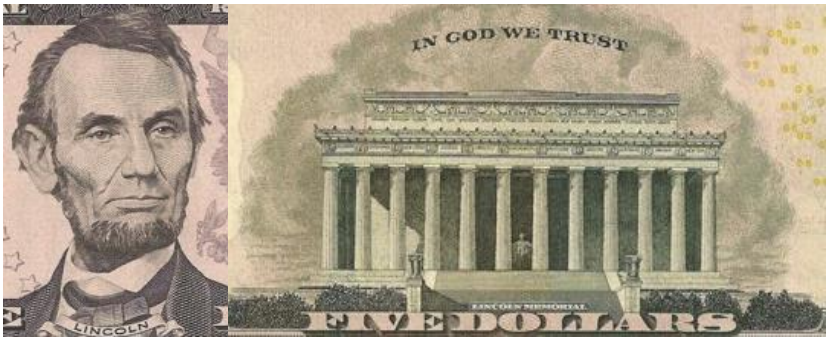


Fig. 47: $5 front/ back side [26]

The $10 banknote has the portrait of Secretary Hamilton on the front side and a vignette of the United States Treasury Building on the back side. [21]

Fig. 48: $10 front/back side [26]

The $20 banknote has the portrait of President Jackson on the front side and a vignette of the White House on the back side. [21]

Fig. 49: $20 front/ back side [26]

The $50 banknote has the portrait of President Grant on the front side and a vignette of the United States Capitol on the back side. [21]

Fig. 50: $50 front/ back side [26]

The $100 banknote has the portrait of Benjamin Franklin on the front side and a vignette of Independence Hall on the back side. [21]

Fig. 51: $100 front/ back side [27]

4.3.7 Serial Numbers

Each U.S. banknote has its specific serial number. It is a unique combination of eleven numbers and letter appears twice on the front side of banknote. [21]

Fig. 52: $50 serial number [16]

4.3.8 Series Years

The $5 banknote contains the design of series year 2006, 2009 and 2013.

The $10 banknote contains the design of series year 2004A, 2006, 2009 and 2013.

The $20 banknote contains the design of series year 2004, 2004A, 2006, 2009 and 2013.

The $50 banknote contains the design of series year 2004, 2004A, 2006 and 2013.

The $100 banknote contains the design of series year 2009 and 2009A. [21]

Fig. 53: $50 Series 2004 [16]

4.3.9 Microprinting

Microprinting has $5 banknote and above. Each banknote has its unique microprinting.

The $5 banknote has small printed text “FIVE DOLLARS” repeated inside the left and right borders, “E PLURIBUS UNUM” at the top of the shield within the Great Seal, and “USA” that is repeated in between the columns of the shield. On the back side, there is the text “USA FIVE” appears along one edge of the large purple numeral 5. [21]

The $10 banknote has small printed text “THE UNITED STATES OF AMERICA” and “TEN DOLLARS USA” below the portrait and inside the borders of the banknote and “USA 10” that is repeated under the torch. [21]

The $20 banknote has small printed text “USA 20” along the border of the first three letters of the blue “TWENTY USA” ribbon to the right of the portrait and “THE UNITED STATES OF AMERICA 20 USA 20” in black in the border below the Treasure’s signature. [21]

The $50 banknote has small printed text “FIFTY, USA and 50” inside two of blue stars to the left of the portrait, “FIFTY” that is repeated within both side borders of the banknote and “THE UNITED STATES OF AMERICA” in President Grant’s collar. [21]

The $100 banknote has small printed text “THE UNITED STATES OF AMERICA” on Benjamin Franklin’s jacket collar, “USA 100” around the blank space containing the portrait watermark, “ONE HUNDRED USA” along the golden quill and small “100s” in the banknote borders. [21]

Fig. 54: $100 microprinting [16]

4.3.10 Symbols of Freedom

Symbol of Freedom has $5 banknote and above. Each banknote has its unique Symbol of Freedom.

The $5 banknote has The Great Seal of United States, featuring an eagle and shield, is printed in purple to the right of the portrait of President Lincoln. An arc of purple stars surrounds the portrait, and the Great Seal. [21]

Fig. 55: The Great Seal of United States [10]

The $10 banknote has the torch carried by the Statue of Liberty and is printed in red to left of the portrait of Secretary Hamilton. A smaller metallic red image of the torch can be found on the lower right side of the portrait. [21]

Fig. 56: The Torch [26]

The $20 banknote has the large blue eagle in the background to the left of President Jackson's portrait. The smaller metallic green eagle to the lower right of the portrait is a more modern engraving. [21]

Fig. 57: The Eagle [26]

The $50 banknote has the Representative of the United States flag, a field of blue stars is situated to the left of the portrait, and meanwhile three red stripes are situated to the right of the portrait. A small metallic silver-blue star is situated on the lower right side of the portrait. [21]

Fig. 58: The Representative of the United States flag/ three red stripes [26]

The $100 banknote has the Phrases from the Declaration of Independence and the quill the Founding Fathers used to sign the historic document can be found to the right of the portrait. [21]

Fig. 59: Declaration of Independence and the Quill [27]

4.3.11 Color

The $5, $10, $20, and $50 banknotes have a unique background color. The large numeral value of denomination helps those with visual impairments distinguish the denomination.

The $5 banknote has the center of the banknote light purple, blending to gray near the edges. [21]

Fig. 60: $5 banknote [26]

The $10 banknote has background colors of orange, yellow, and red. [21]

Fig. 61: $10 banknote [26]

The $20 banknote has background colors of green and peach. The words "TWENTY USA" have been printed in blue colors to the right of the portrait. [21]

Fig. 62: $20 banknote [26]

The $50 banknote has background colors of blue and red to the both sides of the banknote. [21]

Fig. 63: $50 banknote [26]

4.3.12 3-D Security Ribbon

This security feature has only $100 banknote. When you tilt the banknote you will see the bells change to 100s as they move. If you tit banknote side to side, they move up and down. The ribbon is embedded into paper, not printed on it. [21]

Fig. 64: Security Ribbon [16]

4.3.13 Bell in the Inkwell

This security feature has only $100 banknote. When you tilt the banknote you will see the color-shifting bell in the copper inkwell change from copper to green. This effect makes the bell seems to appear and disappear. [21]

Fig. 65: Bell in the Inkwell [16]

4.3.14 UV and IR Fluorescent Ink

Each U.S banknote involves UV and IR fluorescent ink that help to detect genuine banknote under UV light. [11]

Fig. 66: $50 under UV light [28]

Fig. 67: $50 under IR light [28]

4.3.15 Magnetic Ink

Magnetic ink contains ferromagnetic components that provide a specific reaction to the external magnetic field. The components may be added to the ink of any color or colorless item (varnish) of banknote (Chapter 3.3.17). [11]

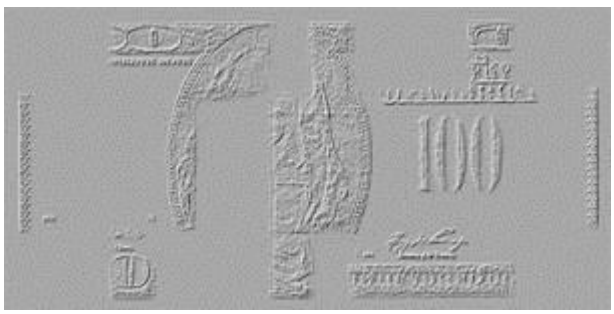


Fig. 68: Magnetic ink on $100[11]

4.3.16 Watermark

Each U.S. banknote involves watermark portrait – depends on specific denomination. [16]

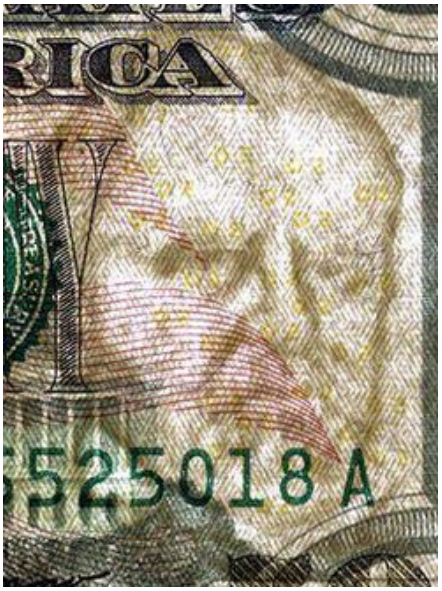


Fig. 69: Watermark on $50 [28]

4.3.17 EURion Constellation

Also known as Omron rings, is a pattern of symbols, especially rings of the same dimension applied against copying (Chapter 3.3.7). [11]

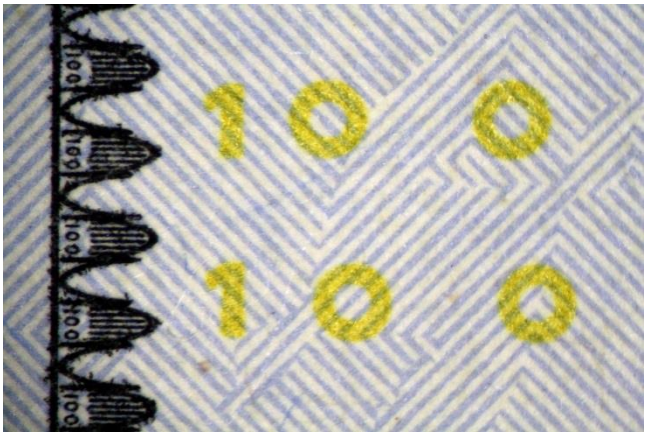


Fig. 70: $100 EURion Constellation

4.3.18 Optical Variable Ink

A special ink based on optically variable pigments. The pigment changes its color according on the angle of light incidence and view (Chapter 3.3.8). [11]

Fig. 71: View at the angle/ view at the accurate angle

4.4 Life Cycle

Before banknotes enter circulation, they must pass through all process, which is consisted from four parts:

- Design.
- Order.
- Production.
- Issuance (and in addition Circulation).

All the process includes close collaboration between the Federal Reserve Board, the Federal Reserve Banks, the U.S. Department of the Treasury´s Bureau of Engraving and Printing, and the U.S. Secret Service. [16]

4.4.1 Design

The design of U.S. currency starts with the design process between the Federal Reserve, the U.S. Department of Treasury´s Bureau of Engraving and Printing, and the U.S. Secret Service. The Secretary of the Treasury has final approval of designs of U.S. currency. [16]

4.4.2 Order

The Federal Reserve Board gives an order for currency from the U.S. Treasury Department´s Bureau of Engraving and Printing every year. This order is based on how much U.S. currency will be demanded by the public in the next year and by how much U.S. currency it expected by Reserve Bank to be destroyed because the banknotes are unfit to circulate or because of another factors, such as inventory, management or the issuance of a new design. [16]

4.4.3 Production

The Bureau of Engraving and Printing receives the print order and manufactures Federal Reserve notes at its facilities in Washington, D.C., and Fort Worth, in Texas. [16]

4.4.4 Issuance

The Federal Reserve Board fund the Bureau of Engraving and Printing for the cost of printing currency as well as fund for the transport (by armored currency transport truck) of the U.S: currency from the Bureau of Engraving and Printing facilities in Washington, D.C., and Forth Worth, Texas, to Federal Reserve Bank cash offices. [16]

4.4.5 Circulation

Federal Reserve Bank cash offices distribute U.S. currency to the public through depository institutions, such as commercial banks, credit unions, and saving and loans associations. [16]

Federal Reserve Banks are responsible for processing banknotes – genuineness of banknotes and suitability for recirculation. If the banknotes are not genuine – counterfeited, Federal Reserve Banks send them to the U.S. Secret Service. On the other hand, if the banknotes are genuine and still in good condition, they are sent to depository institutions to fill new orders for currency. [16]

4.5 The Lifespan of U.S. Currency

The quality of each banknote is evaluated by sophisticated equipment when they are deposited with a Federal Reserve Bank. There is strict quality criteria – if a banknote is still in good condition, it continues to circulate; this banknote, which is taken out of circulation is destroyed. This process defines the lifespan of a Federal Reserve note. [16]

Of course the lifespan of Federal Reserve notes depend on several factors, including how the denomination is used by the public. For example $100 banknotes are often used as a store of value – this banknote is less frequently used, meanwhile lower denomination, such as $5 banknote is more often used for transactions. [16]

Tab. 1: The estimated lifespan of U.S. currency [16]

DENOMINATION	ESTIMATED LIFESPAN
$1	5.8 years
$5	5.5 years
$10	4.5 years
$20	7.9 years
$50	8.5 years
$100	15.0 years

5 CANADIAN DOLLAR

Canadian dollar is not so used as American dollar (only approximately almost 2% in the world) but especially its consistency is completely different. Canadian paper currency is printed on polymer substrate that is more durable than paper .Therefore the Canadian dollar is described in details in following chapter. [32]

5.1 History of Canadian Dollar

The history of Canadian currency began approximately around 1600. Canada was inhabited by the First Nations that used a currency, which is typical for the birth of every world currency, such as strings, belts make from white or purple shells, called "wampum", cooper shield later. After exploration of Canada by Europeans, the Aboriginal people traded with Europeans – they changed their wampum goods for the gold and silver, clothes, weapons, food, etc. Approximately to 1841, Canada was settled, except Aboriginal people, by French and Englishmen that had colonies there. [29]

In 1841 (period of British colonies) when Province of Canada was created, currency reform occurred. The British gold sovereign (a gold coin) was valued at one pound, four shillings, and four pence in local currency, while US$10 gold was valued at two pounds, ten shillings. At the same time, provincial bank was establishes to issue paper currency and it was also the first step to establish the Bank of Canada. [29]

From 1854 to 1914 (the Canadian dollar under the Gold Standard), the value of Canadian dollar was fixed in term of gold and was convertible upon demand. U.S. and British gold coins were legal currency in Canada. Paper currency was freely convertible into gold without restriction. Export and import of gold was not limited. [29]

From 1914 to 1926 (Canada off the Gold Standard), major countries suspended the convertibility of domestic banknotes into gold and the free movement of gold between countries. During this period there were heavy withdrawals of gold from bank. Because of this there were concerns about the possibility of bank runs. This would have an impact to banks - they were legally required to close if they would not able to meet depositor demand for gold. To avoid insolvency, banks issued notes, which were a legal tender. Later, the government also increased the amount of banknotes. [29]

From 1926 to 1931 (Back on the Gold Standard – Temporarily), banks lost their legal tender status. During this period legal tender in Canada were British gold sovereigns and other

current British gold coins, U.S. gold coins and Canadian gold coins and Dominion notes (notes of Province of Canada). Even, silver, nickel, and bronze coins were limited legal tender in Canada. The return back to the gold standard was only short-lived. [29]

From 1930 to 1939 (the Depression Year and the Creation of the Bank of Canada), all people who lived in western of Canada, especially farmers suffered from a sharp fall in both crop yields and prices. These impacts were particularly critical for banks and therefore idea of central bank was born .Generally it was hoped the central bank would be a source of steady and cheap credit and loans. Central bank – Bank of Canada officially started in 1935. [29]

From 1939 to 1950 (Canada under Fixed Exchange Rates and Exchange Controls), Canada need for controls during World War II contrasts with its experience during World War I, when exchange controls were not imposed . Later, The United States had become Canada's most important source of foreign capital, and there was concern that neutral U.S. residents would not wish to hold the securities of a belligerent country. Canadian dollar against its U.S. counterpart the previous year, combined with rising commodity prices associated with the beginning of the Korean War (1950) had significantly strengthened Canada's trade balance with the United States. [29]

From 1962 to 1970 (Return to a Fixed Exchange Rate), Canadian authorities were concerned about deterioration in Canada's international competitiveness, aggravated by its strong dollar, which continued to be supported by substantial capital inflows. Afterwards the investment boom occurred and economic activity had slowed significantly, and the unemployment rate more than doubled (from 3.4% in 1956 to 7.2% in 1961). In this environment, the government sought to ease policy in order to support demand and reduce the economic slack in the economy. [29]

From 1970 to present (Return to a Floating Rate), during this period, including present, Canadian dollar returned to a floating rate. Canadian dollar have a floating rate to American dollar – the value of Canadian dollar comparing to American dollar was permanently changing permanently. Later (in 2002), the Canadian dollar stabilized and then began to recover as the global economy picked up and as the U.S. dollar started to weaken against other currencies. [29]

5.2 History of Canadian Currency Counterfeiting

Counterfeiting of Canadian dollar is not widespread too much because of being not so commonly used tender in the world. The American dollar is the most used currency (approximately 43%),but Canadian dollar is used only by approximately 2% people in the world, so its history of counterfeiting is not too deep as in American dollar case. [16, 32]

Counterfeiting of Canadian currency was not a significant problem until 1992. During 70´s and 80´s, Canada was a center of U.S. currency counterfeiting. Because of U.S. paper currency were mono-colored, in contrast to the colorful Canadian paper currency, making them much easier to counterfeit using the copiers and printers of the time. During 90´s, Canon Inc. developed polychrome (color) photocopying and thanks to this new technology, counterfeiters began to simulate the multicolored Canadian banknotes. [30]

Counterfeiting rapidly changed in 80´s and early 90´s when advanced reprographic system, high-quality and inexpensive graphics software, desktop computers and printers were introduced in the market. The Bank of Canada responded to these new "counterfeiting tools" and increased development of the Optical Security Device (OSD) to defeat banknote counterfeiting on the color copiers. The "Birds of Canada" ("Birds") series of banknotes, released in 1986, were the first series of banknotes, which have the expensive, color-shifting foil square. The OSD worked well for about ten years, until counterfeiters found a way to replicate. [30]

Counterfeiting methodology as the sale of home computers and imaging enhancement software, as well as inject printers, increased dramatically during late 90´s and early 2000s. The high quality, low price, accessibility and ubiquity of these devices made the "Birds" series vulnerable as counterfeiters learned how to use the new technology for making fake banknotes. The problem of Canadian currency counterfeiting grew over the early 2000s and peaking in 2004. From 1998 to 2002, circulation of counterfeit Canadian currency balanced around 100,000 banknotes a year (approximately $5 million), then exploded over to 648,000 banknotes passed in 2004 (approximately $13 million). [30]

Probably the most know example of counterfeit currency involved the $100 "Birds" series banknotes, known also as the "Windsor" or "Weber" notes. Wesley Wayne Weber produced relatively high quality counterfeit $100 banknotes that were spread into several Canadian provinces as well as U.S. and England in 2000. Because of this case, Canadian economy was inundated with counterfeit $100 banknotes and $50 banknotes. From Sep-

tember 2007 almost $7.68 million worth of Weber's counterfeits entered into circulation. [30]

The Bank of Canada released a new series of banknotes, the "Canadian Journey" (CJ) series, in $5 and $10 denomination, in 2001. These new banknotes had very security features. Later, in 2004, became "Canadian Journey (stripes)" (CJs) series, which was introduced with additional security features – the holographic stripe, security thread and micro-printing. The NCES (National Counterfeit Enforcement Strategy) as well as the Bank of Canada provided public awareness and education campaigns to assist in counterfeit prevention. All these combinations of better security features, public awareness and prevention led to significant decline in currency counterfeiting in Canada since 2004. [30]

Fig. 72: $100 genuine vs. counterfeit [31]

5.3 Security Features

Security features are important elements to disable counterfeit banknotes. Each banknote has its specific security features that are described below. Despite of U.S. banknotes, where $100 banknotes have the most sophisticated security features, all Canadian banknotes have the same security features but still they are very sophisticated and well embedded, and almost impossible to counterfeit them without appropriate machines and tools.

5.3.1 Raised Printing

When you move your finger along the banknote's surface you can feel the raised printing that gives genuine Federal Reserve banknotes their distinctive texture. Raised printing has all Canadian banknotes. Raised printing can be left on the denomination value, shoulder of person´s portrait and on the "BANQUE DU CANADA". [33]

Fig. 73: Raised printing on $5 [33]

5.3.2 Large Window

Large Window is a transparent window (can be viewed through) that containing a metallic portrait and building. Every Canadian banknote has its own metallic portrait and building. This security features have all Canadian banknotes. [33]

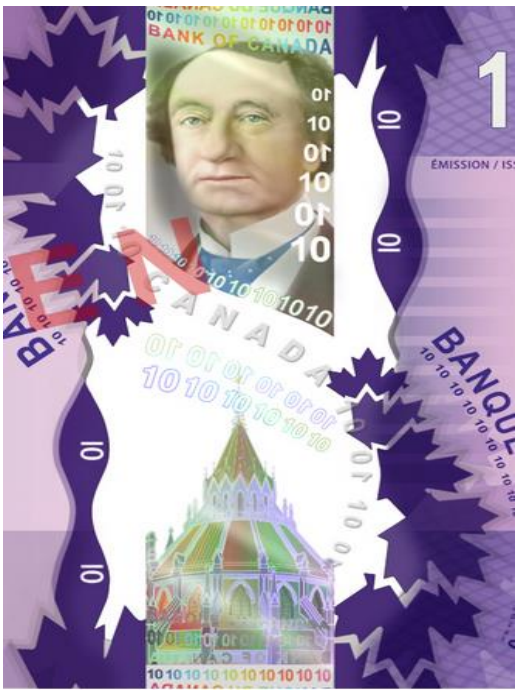


Fig. 74: Large Window on $10 [33]

5.3.3 Portrait and Symbols

Each Canadian banknote has its own portrait of famous Canadian character and specific symbols.

The $5 banknote has the portrait of Sir Wilfrid Laurier (Prime Minister) on the front side and Mobile Servicing System: Canadarm 2, Dextre and the Mobile Base; Astronaut; Earth; and Stars on the back side. [33]

Fig. 75: $5 front side/ back side [33]

The $10 banknote has the portrait of Sir John A. Macdonald (the first Prime Minister) on the front side and The Canadian Train, The Canadian Rockies, and Canada's Passenger Rail Network on the back side. [33]

Fig. 76: $10 front side/ back side [33]

The $20 banknote has the portrait of Queen of Elizabeth II on the front side and The Canadian National Vimy Memorial, Poppies, and The Canadian Flag on the back side. [33]

Fig. 77: $20 front side/ back side [33]

The $50 banknote has the portrait of William Lyon Mackenzie King (the longest serving Prime Minister) on the front side and CCGS Amundsen, Research Icebreaker; “Arctic” in Inuktitut; and Map of Canada’s Northern Regions on the back side. [33]

Fig. 78: $50 front side/ back side [33]

The $100 has the portrait of Sir Robert Borden (8th Prime Minister during the WWI) on the front side and Research at a Microscope, Insulin, and DNA Strand on the back side. [33]

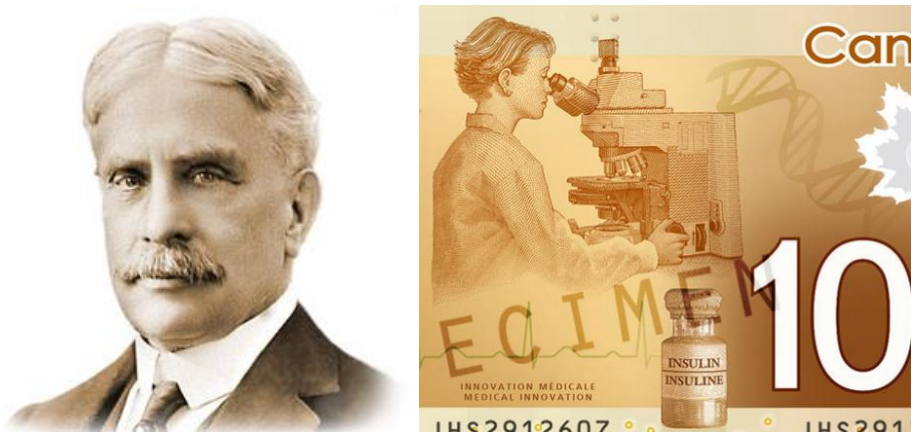


Fig. 79: $100 front side/ back side [33]

5.3.4 Substrate

Canadian banknotes are currently made from polymer substrate that has several advantages compares with paper. All advantages and disadvantages are described in previous chapter (Chapter 3.1.2).

5.3.5 Metallic Symbols

Each Canadian banknote has its own transparent window with metallic portrait and metallic building. Metallic symbols are viewed from both sides of banknote.

The $5 banknote has the portrait of Sir Wilfrid Laurier and The West Block of Parliament original construction. [33]

Fig. 80: $5 metallic symbols [33]

5.3.6 Serial Numbers

The $10 banknote has the portrait of John A. Macdonald and The Library of Parliament. [33]

Fig. 81: $10 metallic symbols [33]

The $20 banknote has the portrait of Queen Elizabeth II and The Peace Tower. [33]

Fig. 82: $20 metallic symbols [33]

The $50 banknote has the portrait of William Lyon Mackenzie King and The Center Block of Parliament. [33]

Fig. 83: $50 metallic symbols [33]

The $100 banknote has the portrait of Sir Robert Borden and The East Block. [33]

Fig. 84: $100 metallic symbols [33]

5.3.7 Serial Numbers

Each Canadian banknote has its specific serial number. It is a unique combination of ten numbers and letter appears twice on the back side of banknote. [33]

Fig. 85: Serial number of $100 [33]

5.3.8 Micro-printing

Each Canadian banknote has its own specific micro-printing and fine lines. For example micro-printing – small numbers can be found in large window. [33]

Fig. 86: Micro-printing of denomination "5" value [34]

5.3.9 Color

Each Canadian banknote has its own specific color. The color and large numeral value of denomination helps those with visual impairments distinguish the denomination. [33]

The $5 banknote has the shades of blue. [33]

Fig. 87: $5 banknote [33]

The $10 banknote has the shades of purple. [33]

Fig. 88: $10 banknote [33]

The $20 banknote has the shades of green. [33]

Fig. 89: $20 banknote [33]

The $50 banknote has the shades of red. [33]

Fig. 90: $50 banknote [33]

The $100 banknote has the shades of brown. [33]

Fig. 91: $100 banknote [33]

5.3.10 Transparent Text

The text can be also found in the large window. It feels slightly raised. [33]

Fig. 92: Transparent text "CANADA" [33]

5.3.11 Maple Leaf Border

Maple leaves that border and cross into the large window. [33]

Fig. 93: Maple leaf border [33]

5.3.12 Frosted Maple Leaf

Frosted maple leaf is placed on the left from the portrait and involves the transparent outline. [33]

Fig. 94: Frosted maple leaf [33]

5.3.13 Hidden Numbers

Hidden numbers are placed into maple leaf that is on the left from the portrait. They are viewed when you look through the leaf. [33]

Fig. 95: Hidden numbers [33]

5.3.14 Braille

Each Canadian banknote involves the Braille that helps those with visual impairments distinguish the denomination. [33]

Fig. 96: Braille on $20 [33]

5.3.15 EURion Constellation

Each Canadian banknote involves EURion constellation (on the back side) that prevent copying banknotes on the copiers. [33]

Fig. 97: EURion constellation [33]

5.3.16 UV and IR Fluorescent Ink

Each Canadian banknote involves UV and IR fluorescent ink that help to detect genuine banknote under UV light. [34]

Fig. 98: $50 under UV light [34]

Fig. 99: $50 under IR light [34]

5.3.17 Magnetic Ink

Magnetic ink contains ferromagnetic components that provide a specific reaction to the external magnetic field. The components may be added to the ink of any color or colorless item (varnish) of banknote (Chapter 3.3.17). [11]

Fig. 100: Magnetic ink of $5[34]

5.4 Life Cycle

The life cycle of Canadian banknotes is similar to U.S. banknotes – design, order, production, issuance and circulation. Because of Canadian banknotes are made from another substrate than U.S. banknotes, they have more advantages. [35]

Polymer banknotes have several benefits over the current design (based on cotton paper substrate) because of:

1. *Manufacturing* – an increased lifetime compared to the cotton paper banknotes has a lower overall impact; even if the manufacturing of one polymer banknote has a higher environmental impact, the fact that it takes longer offsets this effect.
2. *Distribution* – the polymer banknote must be transported 2.5 less times than ordinary cotton paper banknotes. Because of its extender lifetime, it requires less transport of fresh banknotes to the system, and fewer until banknotes sent back to the backing system. The weight of polymer banknotes is lighter – shipments are

limited by value and not weight – a lighter weight of banknotes show environmental benefit over time.

3. *End-of-life* – the polymer banknotes are mostly made of inactive carbon, which in contrary to cotton paper, does not contribute to GHG emission on landfill.

The longer the polymer banknotes are in circulation, the greater the advantage of polymer compares to the cotton paper banknotes. [35]

Tab. 2: Canadian banknotes weight, lifetime and thickness [35]

	Weight (kg/ 100 banknotes)	**Lifetime (years)**	**Thickness (µm)**
Cotton paper banknote	0.102	3	115
Polymer banknote	0.093	7.5	91

6 LUMINESCENCE SPECTROSCOPY

Luminescence is a phenomenon when any substance emits light when sufficient amount of energy is delivered. Spectroscopy is a physic field, which studies spectrums features. And therefore the term "Luminescence Spectroscopy" means an exploration of luminescence features in the particular spectrum part. [36]

Because of low level of the detected light radiation, it is necessary that spectral equipment has the appropriate detector (with the highest level of lightness and sensitivity) and effective optical collection system of the luminescence radiation as well. [36]

6.1 Principle of Luminescence

The principle of luminescence is based on delivery sufficient amount of energy to any substance – electrons are excited to higher energetic levels where absorption of electron excitation energy occurs. In a simplified way can be said that energy is transformed into luminescence radiation (visible light region). Luminescence fades out in a certain time when excitation energy is removed. This time usually ranges in femtoseconds (10^{-15}) or nanoseconds up to several hours in some cases. [36]

6.2 Types of Luminescence

According to how excitation energy is delivered, here are distinguished an energy sources as follows:

- Photoluminescence – the energy is excited by a light source.
- Electroluminescence – the energy is excited by an electric field.
- Chemiluminescence – the energy is excited by a chemical reaction.
- Cathodoluminescence – the energy is excited by impinging electrons.
- Mechanoluminescence – the energy is excited by a mechanic action.
- Thermoluminescence – the energy is excited by a thermal energy, usually after previous excitation of another way. [36]

Luminescence is divided as follows:

- Fluorescence – occurs when luminescence fades out immediately from a substance, which is illuminated.

- Phosphorescence – occurs when luminescence remains on a substance when energy source is removed. [36]

6.3 Application of Luminescence

Luminescence has a huge range of applications such as follows:

a) *Textiles, papers and dyes* – many of white textiles and papers involve in its structure fluorescing substances, which have yellow shade on the daylight. These impregnated substances mostly illuminate under UV light blue-white color. Textiles emit by the same color, which involves in its structure fluorescent dyes. [37]

b) *Minerals, plant oils and fats* – fats and mineral oils emit strong blue, almost green, luminescence. On the other hand plant oils emit weak radiations under UV light. [37]

c) *Detection of counterfeits* – banknotes, cheques, postal stamps or other stamp (high way stamps etc.) contain unique sequence of numbers or microprinting, which are filled with luminophores and provide identification if they are genuine or not. [37]

d) *Food industry* – a fresh milk and butter emits yellow fluorescence, later on blue one. Fresh albumen does not emit any fluorescence but it will emit blue color when it will get older. [37]

e) *Organic compounds and dyes* – only aromatized compounds emit fluorescence. [37]

f) *Detection of counterfeited banknotes* – not only detectors can detect counterfeited banknote but scientist methods can do it as well. For example Detection of counterfeit money using intrinsic fluorescent life time. This method is based on different fluorescent life time in genuine and counterfeited banknotes. There are also microscopy methods that can be used to detection (to detect a fake camera chips, semiconductors and other electronic components). [38, 39]

II. ANALYSIS

7 INTRODUCTION TO MEASUREMENT

All process of research contains photos of banknotes on daylight, when passing daylight, under UV lamp, under stereomicroscope and the final part, spectrofluorometer analysis. Photos of banknotes are focused on all security features but mainly on features that contain luminophores. These banknotes are examined on the spectrofluorometer. All banknotes were examined with the same conditions.

Photos of all banknotes on daylight were recorded by camera Nikon Coolpix P80 with tripod. All banknotes within ultraviolet electromagnetic spectrum were examined inside handmade photo box by previously mentioned camera, tripod and UV handle lamp Krüss UV240 (two wavelengths – 254 nm and 366 nm). Some photos are recorded only from the front side, some from the front and back side – this depends on the specific purpose of analysis.

As the kind of security features are the same for all American and all Canadian polymer banknotes have the same security features (banknotes (Chapter 5.3) regardless on denomination, only key security features were recorded by stereomicroscope Zeiss Stemi 2000-C with camera Canon EOS 100D and PC with software AxioVision. Photos were recorded with different magnification which is written in output analysis by every photo.

Spectrofluorometer analysis was executed using Photon Counting Steady-State Spectrofluorometer PC1 made by ISS Company, with PC and software VINCI. Excitation energy was 254 nm because the luminescence of security features was stronger on this wavelength than on 366 nm wavelength. Spectrofluorometer is able to measure from approximately 200 nm to 600 nm and therefore the examined spectrum was in range of 300 nm to 600 nm (there was not any luminescence under 300 nm). The output of spectrofluorometer is dependence of the intensity at the emission wavelength of the luminescent radiation.

8 AMERICAN DOLLAR

This chapter deals with American dollar analysis. Photos of banknotes and outputs from spectrofluorometer with previously mentioned conditions (Chapter 7) are included. As it mentioned previously, all security features have the same character and therefore only key features, mostly on the $100 banknote, are recorded.

8.1 1 USD

The $1 old emission (1995) and the $1 new emission (2013) were examined.

Fig. 101: 1 USD 1995/ 2013 on daylight

Fig. 102: 1 USD 1995/ 2013 when passing daylight

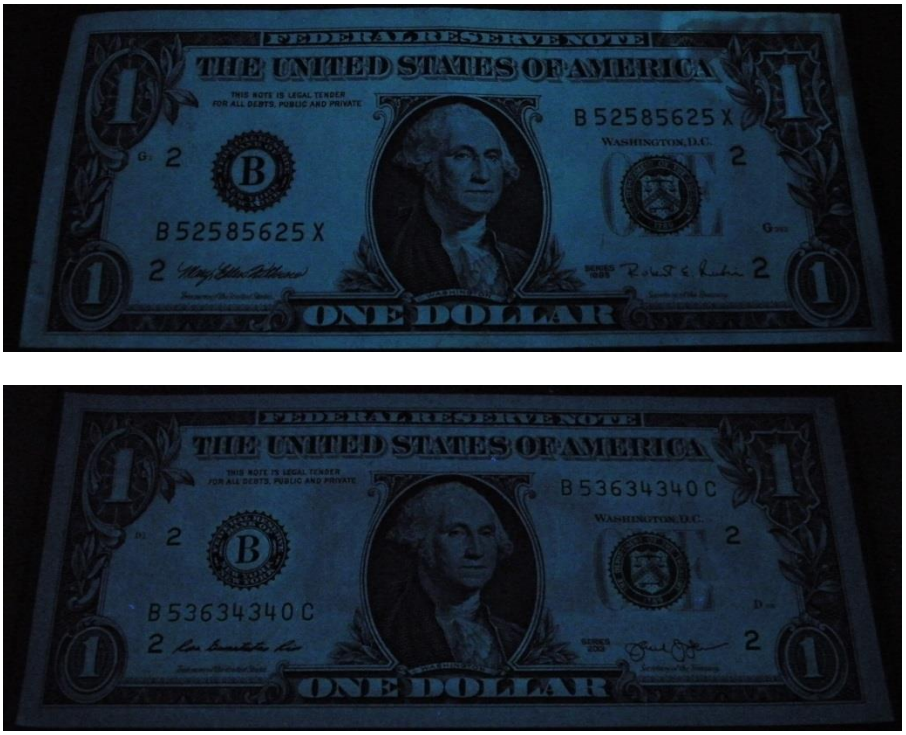
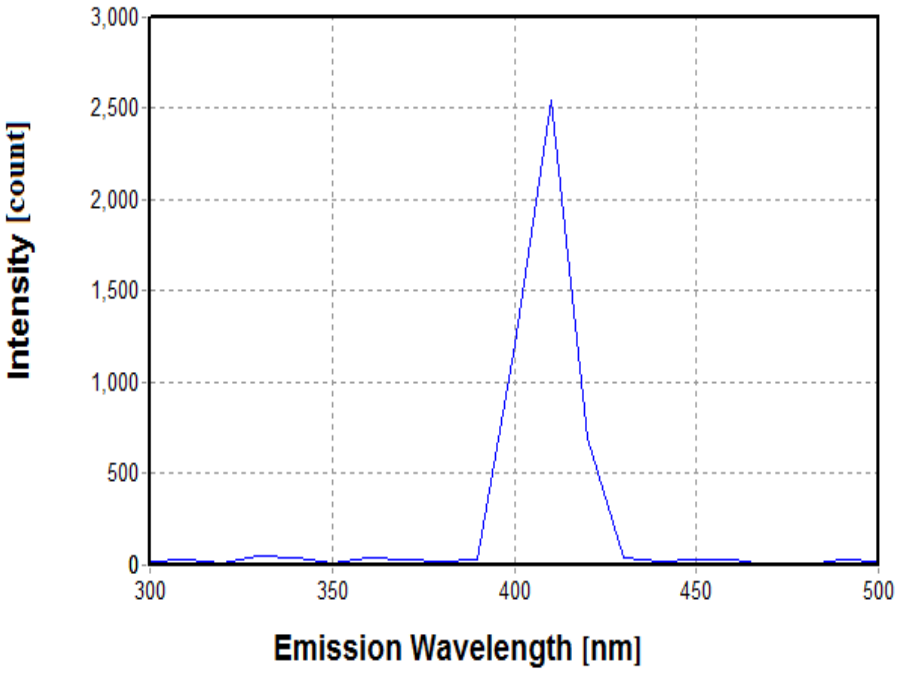
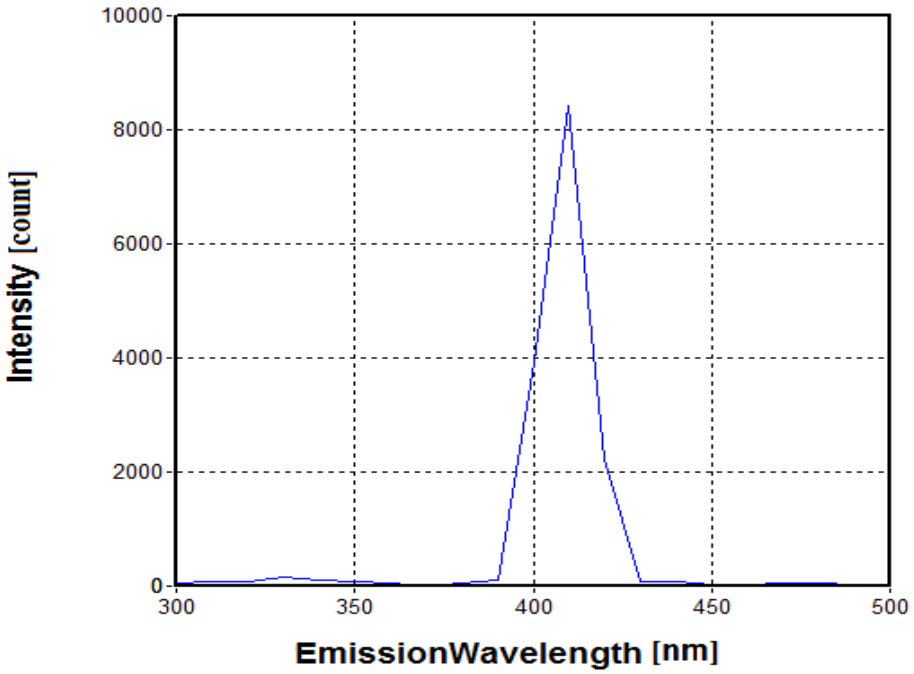


Fig. 103: 1 USD 1995/ 2013 irradiated by 254 nm

Fig. 104: 1 USD 1995/ 2013 irradiated by 366 nm

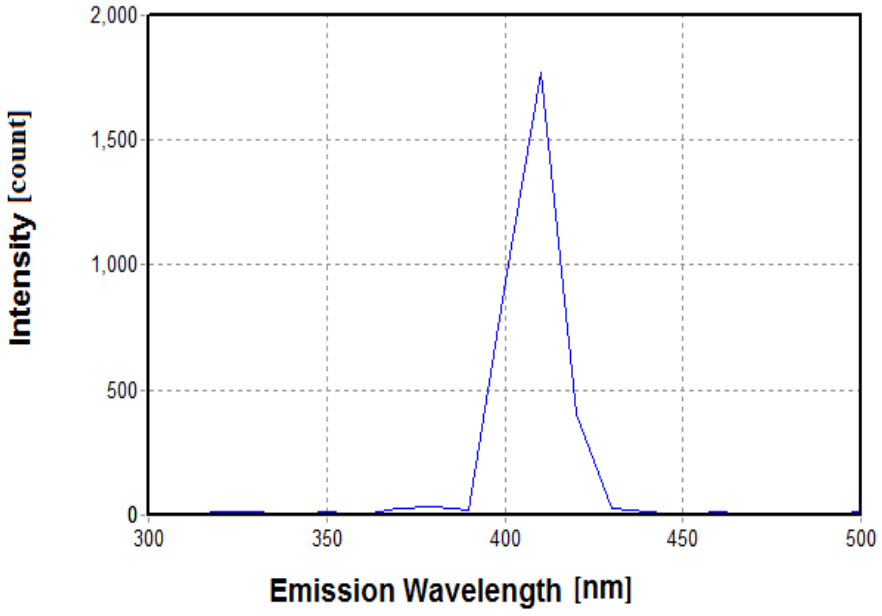
As it can be seen, the $1 old emission and new emission looks very similar. They have the same security features. On the other hand they do not contain any security features with luminophores. Only the $1 old emission shows little luminescence on the upper right corner but this is only a kind of dirt gained from circulation. The background – paper substrate shows stronger luminescence against the ink area.

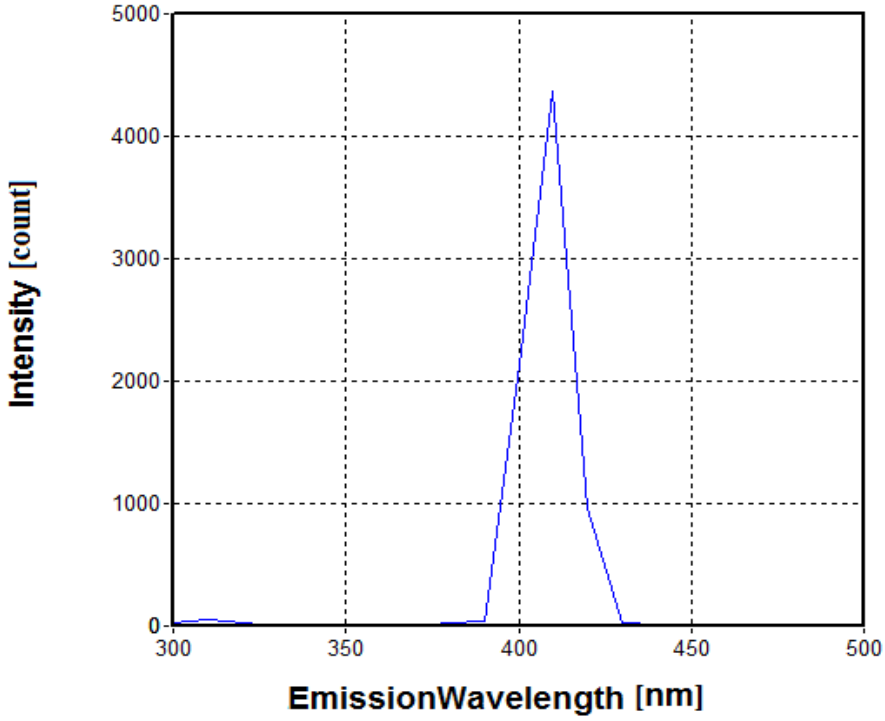




Graph 1: 1 USD 1995/ 2013 paper substrate

As it can be seen in Graph 1, the luminescence spectrum is almost the same – with the peak is around 410 nm the intensity of luminescence being weaker on the older banknote.





Graph 2: 1 USD 1995/ 2013 Treasury Seal

In Graph 2, the luminescence spectrum of banknote from 1995/2013 emission is almost the same – the peak is around 410 nm but luminescence intensity is weaker on the older banknote. On the other hand, the luminescence intensity measured on ink area (Treasury Seal) is weaker than in Graph 1.

8.2 2 USD

The $2 new emission - from 2009 was examined.

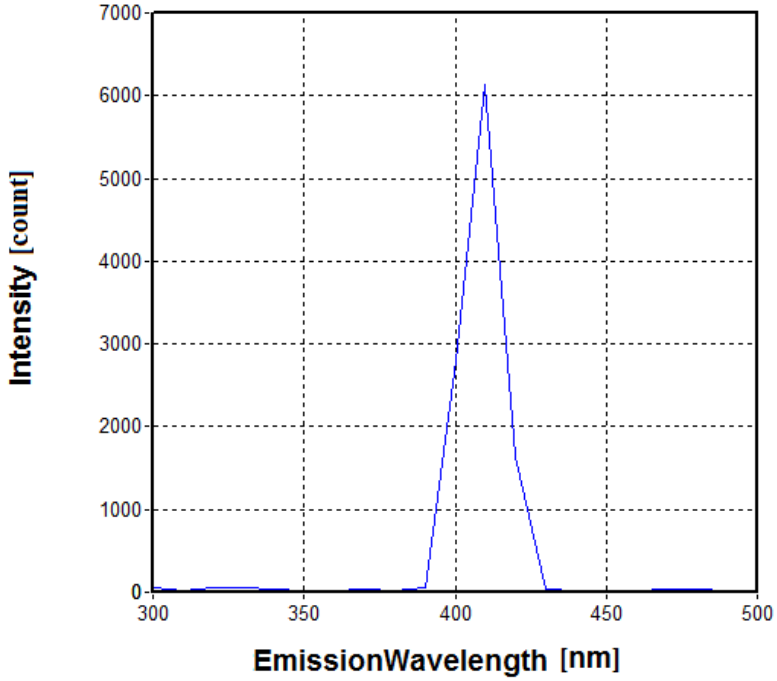
Fig. 105: 2 USD on daylight

Fig. 106: 2 USD when passing daylight

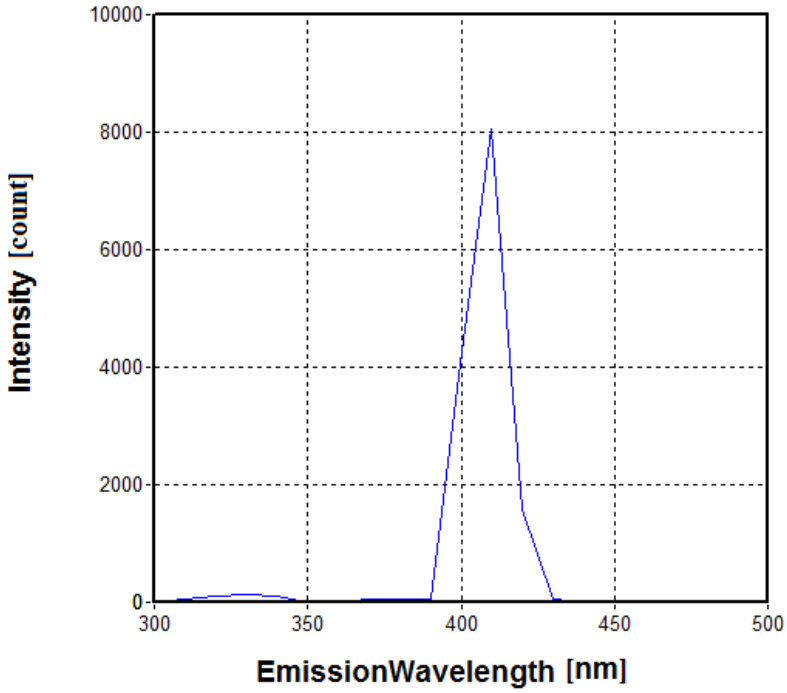
Fig. 107: 2 USD irradiated by 254 nm

Fig. 108: 2 USD irradiated by 366 nm

As it can be seen, the $2 banknote does not contain any security features with luminophores. Only in the Figure 107, on the whole bottom of length of banknote and on the left from Federal Reserve Seal are elements that evince luminescence compared to background. This are not any security features but only a kind of dirt gained from circulation. The background – paper substrate evinces stronger luminescence compared to the ink area.



Graph 3: 2 USD paper substrate



Graph 4: 2 USD Treasury Seal

As it can be seen in Graph 3 and Graph 4, the luminescence spectrum of paper and ink area looks very similar with the peak around 410 nm. On the other hand, the luminescence intensity of paper is weaker than luminescence intensity of ink area.

8.3 5 USD

The $5 old emission (1988) and the $5 new emission (2013) were examined.

Fig. 109: 5 USD 1988/ 2013 on daylight

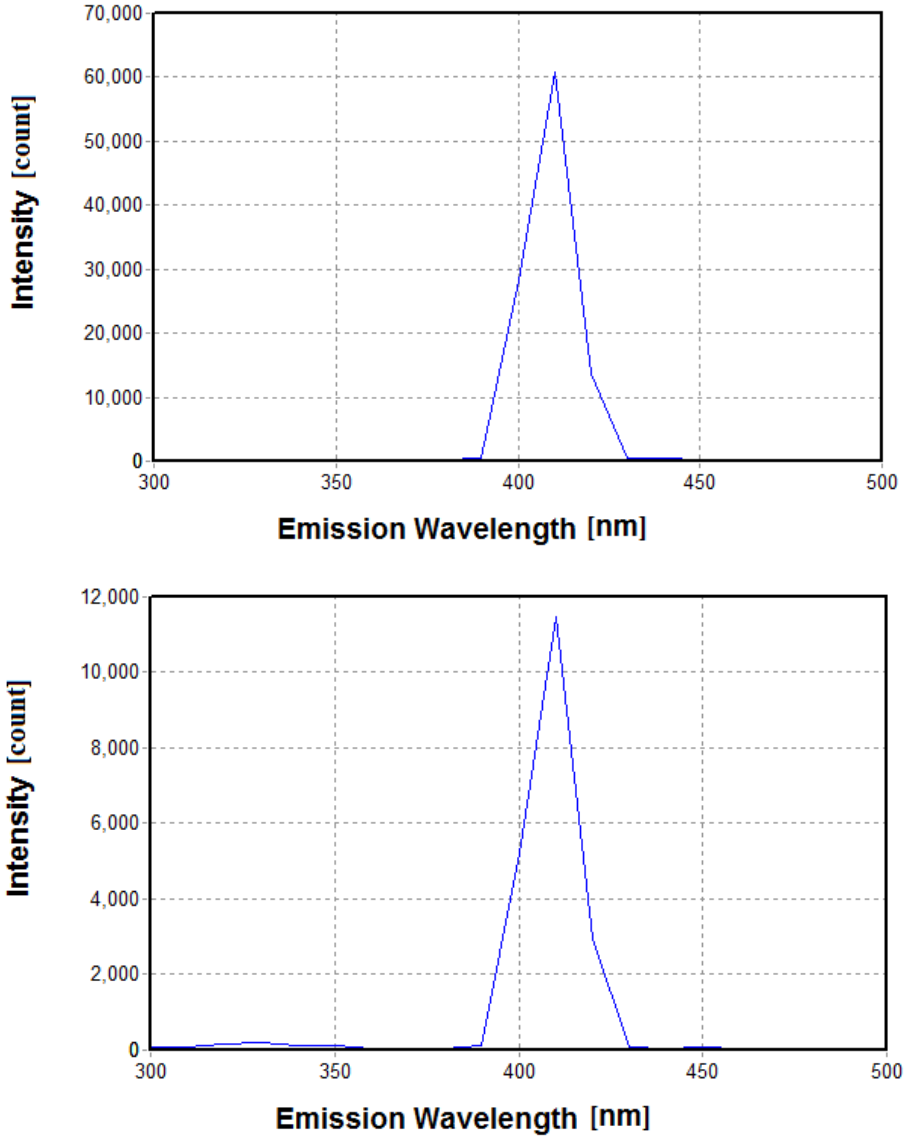
Fig. 110: 5 USD 1988/ 2013 when passing daylight

Fig. 111: 5 USD 1988/ 2013 irradiated by 254 nm

Fig. 112: 5 USD 1988/ 2013 irradiated by 366 nm

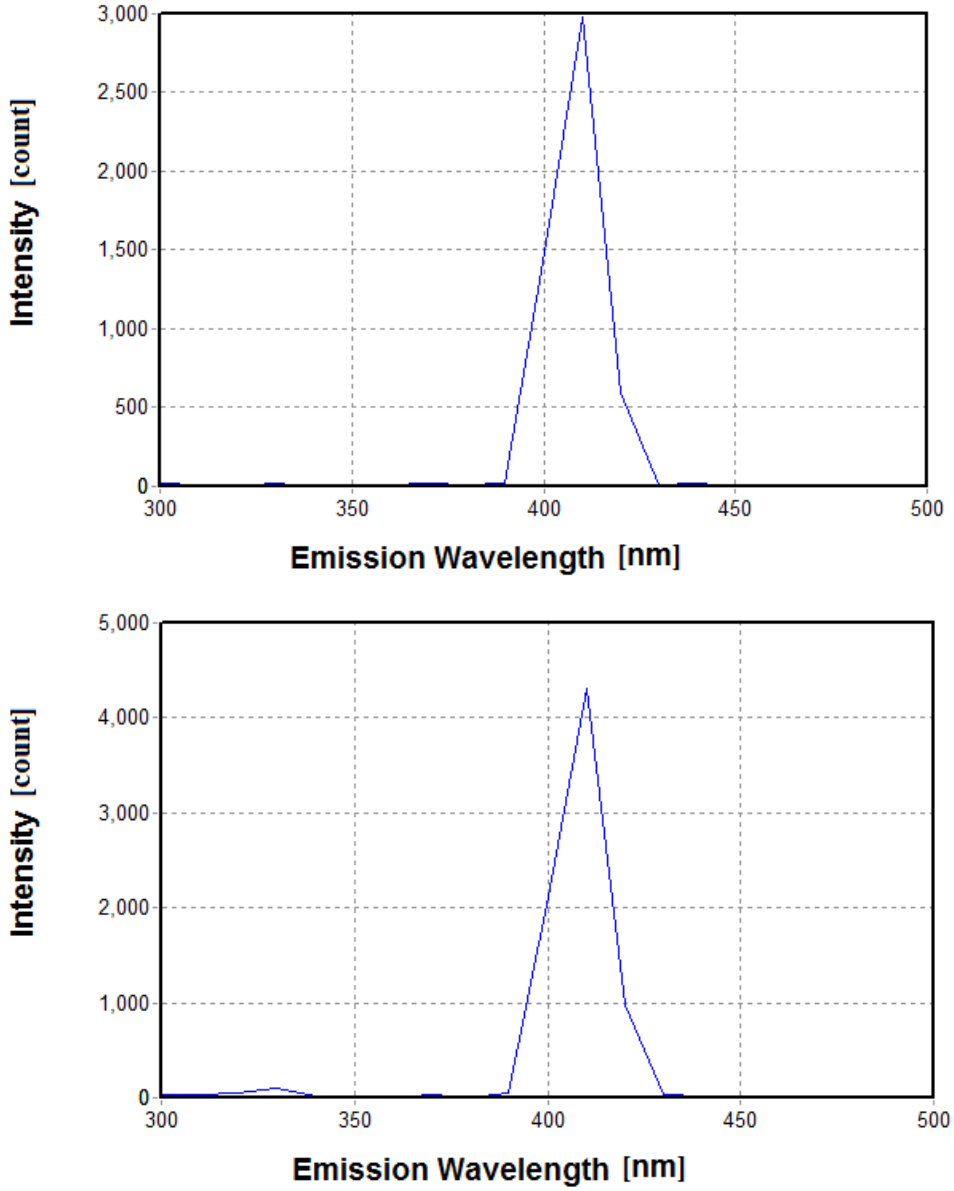
The $5 banknote was completely redesigned. New banknote contains additional security features such as protection against copying (EURion constellation) watermark and security thread (as well as other banknote from the $5 and above). Federal Reserve Seal on the left of banknote was replaced by Federal Reserve System Seal.

The new $5 banknote contains security thread that is visible within UV spectrum on 254 nm wavelength. On 366 nm wavelength is not visible at all (see Figure 112).



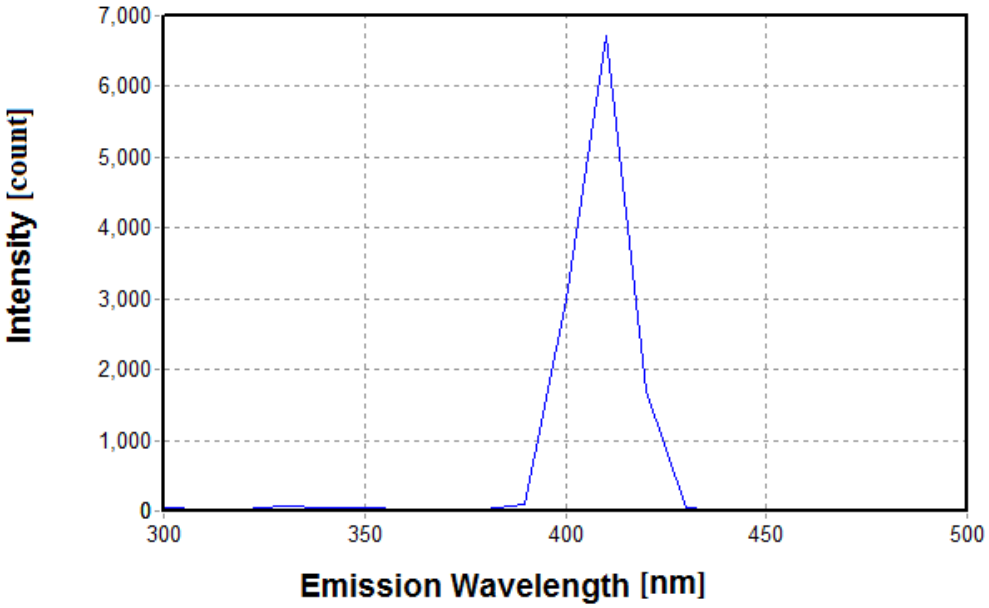
Graph 5: 5 USD 1988/ 2013 paper substrate

As it can be seen in Graph 5, the luminescence spectrum of the $5 banknotes looks similar with the peak around 410 nm but the luminescence intensity of the older banknote is much stronger than luminescence intensity of the newer banknote. This may be caused by wearing out of the old banknote due to circulation (human sweat and oily secretion and other liquids).



Graph 6: 5 USD 1988/ 2013 Treasury Seal

In Graph 6, the luminescence spectrum of both banknotes looks almost the same with the peak around 410 nm but the luminescence intensity of inked area is a little bit stronger on the newer banknote than on the older one. On the other hand, the luminescence intensity of ink area is weaker than luminescence intensity of paper substrate (see Graph 5).



Graph 7: 5 USD 2013 Security Thread

Graph 7 shows the luminescence spectrum of security thread looks almost the same as previous spectrums, with the peak around 410 nm. The luminescence intensity of security thread is stronger than intensity of ink area but weaker than the luminescence intensity of paper substrate. This fact is very strange because security thread evinced stronger luminescence (on 254 nm wavelength) than paper substrate. This fact may be caused by measurement errors such as too much large an amount of excitation energy (excitation beam), an angle of incident that goes to the evaluation unit of spectroflurometer and so on.

8.4 10 USD

The $10 new emission - from 2013 was examined.

Fig. 113: 10 USD on daylight

Fig. 114: 10 USD when passing daylight

Fig. 115: 10 USD irradiated by 254 nm

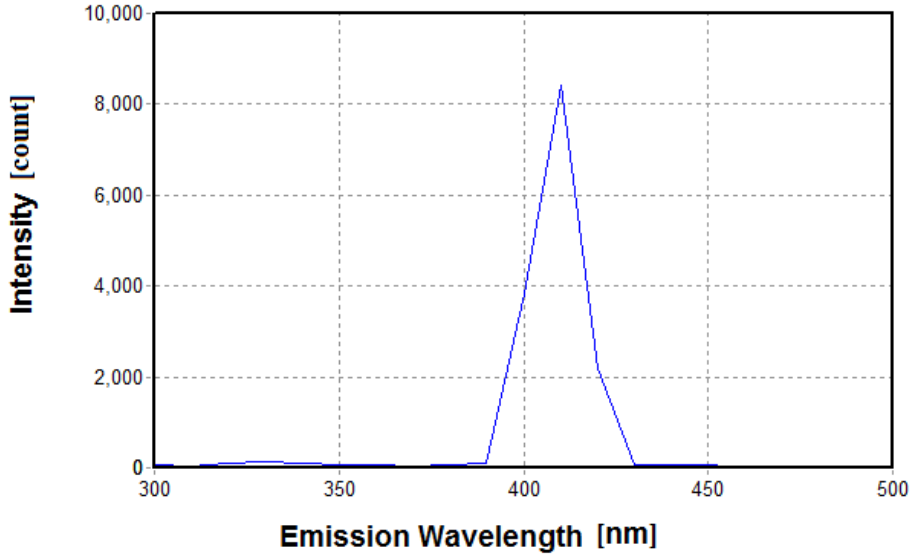
Fig. 116: 10 USD irradiated by 366 nm

As it can be seen, the $10 banknote contains security thread that is clearly visible when irradiated by 254 nm wavelength. It is not visible when irradiated by 366 nm wavelength at all.

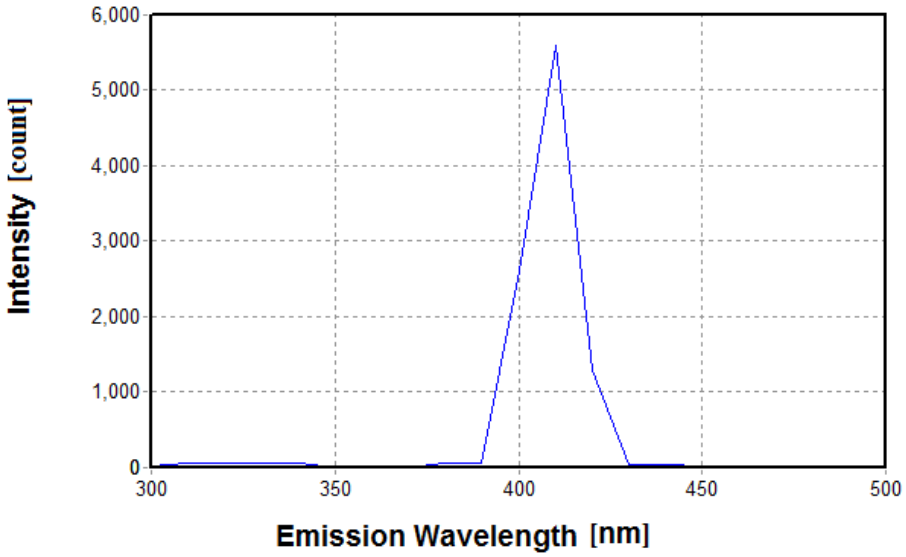
As the $10 banknote is higher denomination than the $1, the $2 and the $5 banknotes and therefore it contains additional security features –optical variable ink – the denomination value “10” on the right lower corner, iridescent ink - the symbol of freedom – “The Torch” on the right shoulder of the portrait (see Figure 117; 12.5x and 50x magnification) and protection against copying, as the $5 banknote (see Figure 118; 25x magnification).

Fig. 117: The Torch

Fig. 118: 10 USD feature against copying



Graph 8: 10 USD paper substrate



Graph 9: 10 USD Security Thread

As it can be seen in Graph 8 and Graph 9, the luminescence spectrums are almost the same with the peak around 410 nm. On the other hand the luminescence intensity is stronger in Graph 8 – paper substrate. This fact is very strange because security thread has evinced stronger luminescence (on 254 nm wavelength) than paper substrate. This fact may by causes by measurement errors such as too much large an amount of excitation energy (excitation beam), an angle of incident beam that goes to the evaluation unit of spectroflurometer and other.

8.5 20 USD

The $20 new emission - from 2013 was examined.

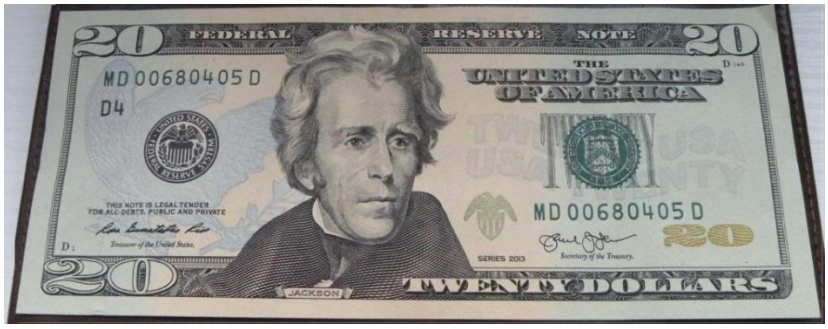


Fig. 119: 20 USD on daylight

Fig. 120: 20 USD when passing daylight

Fig. 121: 20 USD irradiated by 254 nm

Fig. 122: 20 USD irradiated by 366 nm

As it can be seen, the $20 banknote contains security thread that is clearly visible when irradiated by 254 nm wavelength. It is not visible when irradiated by 366 nm wavelength at all.

As the $20 banknote is higher denomination than the $1, the $2 and the $5 banknotes and therefore it contains additional security features –optical variable ink – the denomination value "20" on the right lower corner, iridescent ink - the symbol of freedom – "The Eagle" on the right shoulder of the portrait (Figure 123; 12.5x and 50x magnification) and protection against copying, as the $5 and the $10 banknote (Figure 124; 16x magnification).

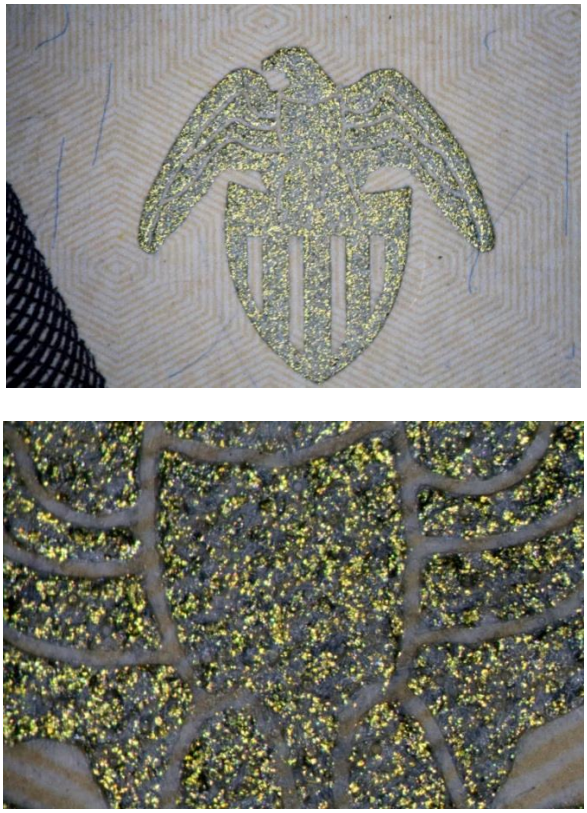


Fig. 123: The Eagle

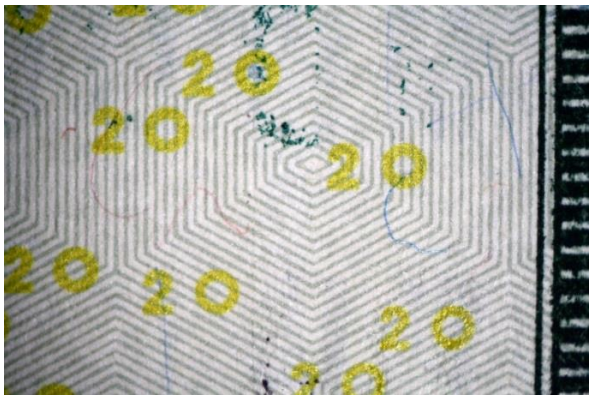
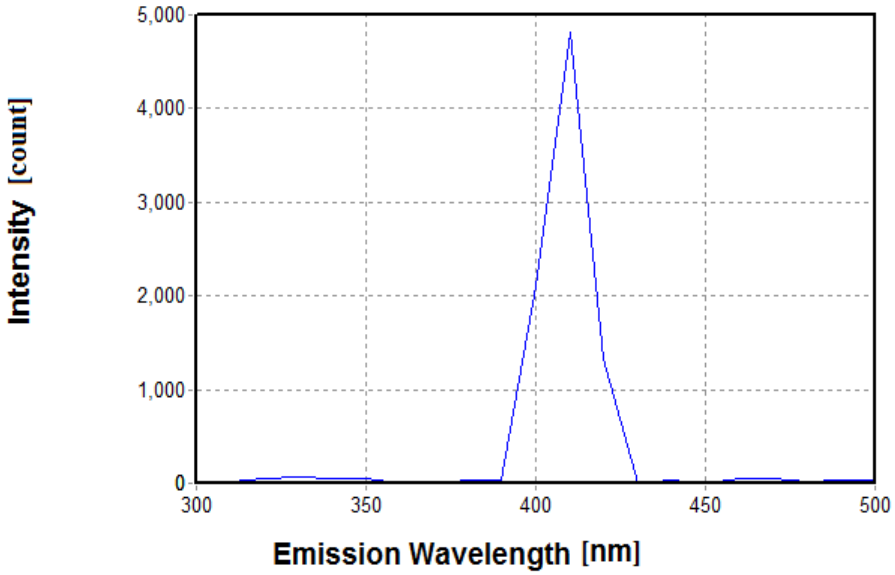
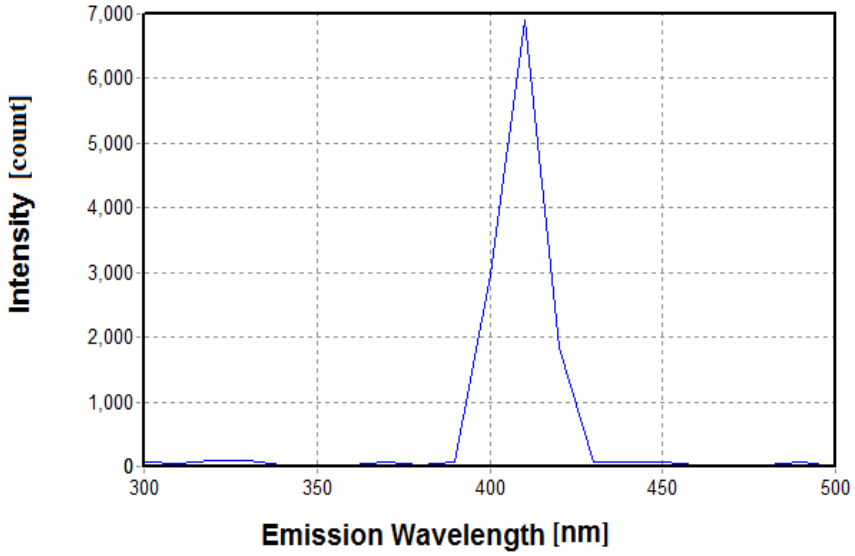


Fig. 124: 20 USD feature against copying



Graph 10: 20 USD paper substrate



Graph 11: 20 USD Security Thread

As it can be seen in Graph 10 and Graph 11, the luminescence spectrums are almost the same, the peak being around 410 nm. On the other hand the luminescence intensity is stronger in Graph 11 – security thread. This fact is relevant because security thread evince stronger luminescence intensity than background of the banknote (see Figure 121).

8.6 50 USD

The $50 new emission - from 2013 was examined

Fig. 125: 50 USD on daylight

Fig. 126: 50 USD when passing daylight

Fig. 127: 50 USD irradiated by 254 nm

Fig. 128: 50 USD irradiated by 366 nm

As it can be seen, the $50 banknote contains security thread that is clearly visible when irradiated by 254 nm wavelength. It is lightly visible when irradiated by 366 nm wavelength as well.

As the $50 banknote is higher denomination than the $1, the $2 and the $5 banknotes (and therefore) it contains additional security features –optical variable ink – the denomination value “50” (see Figure 129; 10x magnification) on the right lower corner, iridescent ink - the symbol of freedom – “The Star” on the right shoulder of the portrait (see Figure 130; 12.5x and 50x magnification) and protection against copying, as the $5, the 10$ and the 20$ banknote.

Fig. 129: 50 USD – view at the right and an accurate angle

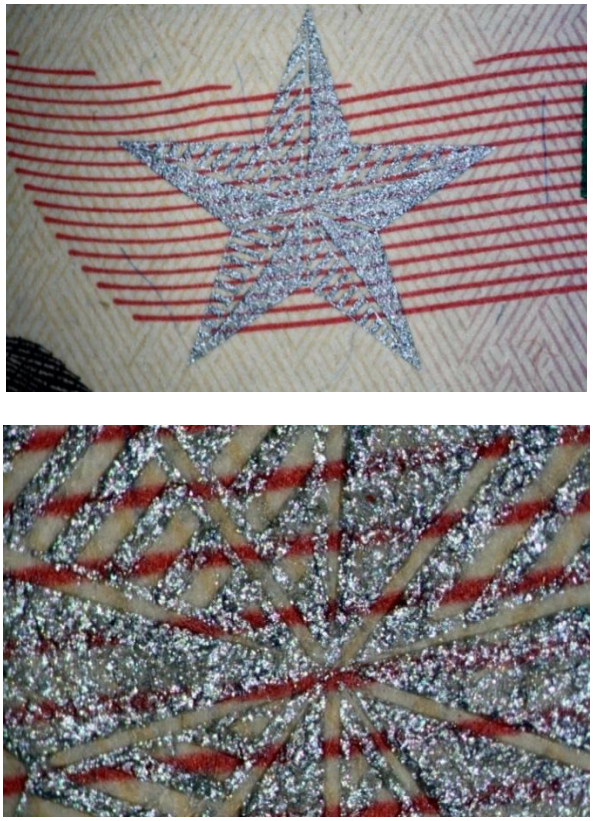
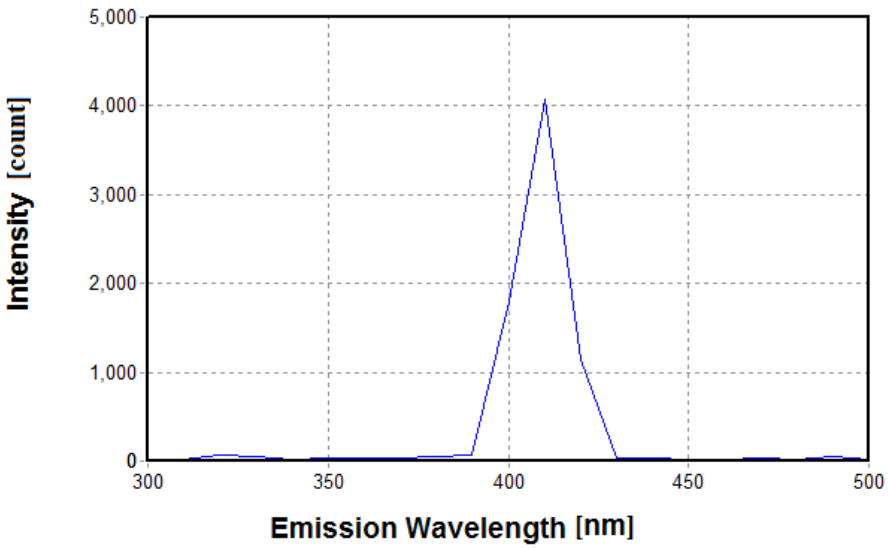
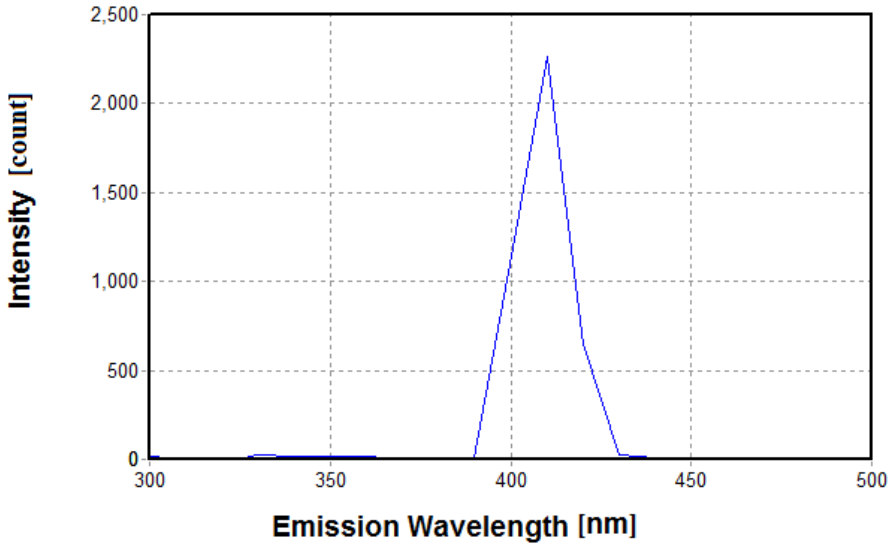


Fig. 130: The Star



Graph 12: 50 USD paper substrate



Graph 13: 50 USD Security Thread

As it can be seen in Graph 12 and Graph 13, the luminescence spectrums are almost the same with the peak around 410 nm. On the other hand the luminescence intensity is stronger in Graph 12 – paper substrate. This fact is very strange because security thread evinced much stronger luminescence (on 254 nm wavelength) than paper substrate. This fact may be due to measurement errors such as too large an amount of excitation energy (excitation beam), an angle of incident beam that goes to the evaluation unit of spectrofluorometer and other.

8.7 100 USD

The $100 new emission - from 2009 was examined. As the $100 banknote represents the highest value of U.S. currency and contains the most sophisticated security features from all U.S. currency, it is examined deeper than previous banknotes.

Fig. 131: 100 USD on daylight (front and back side)

Fig. 132: 100 USD when passing daylight (front and back side)

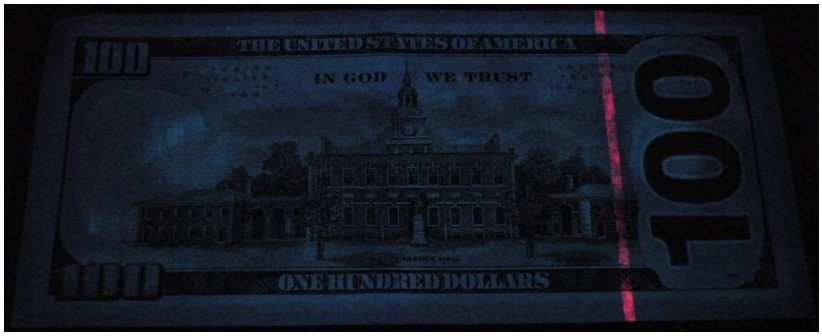


Fig. 133: 100 USD irradiated by 254 nm (front and back side)

Fig. 134: 100 USD irradiated by 366 nm (front and back side)

As may be seen, the $100 banknote contains security thread that is not almost visible from the front side (like previous banknotes) when irradiated by 254 nm wavelength but it is clearly visible from the back side. It is not visible when irradiated by 366 nm wavelength at all.

As the $100 banknote is the highest denomination from all U.S. banknote, therefore it contains additional security features –optical variable ink – the denomination value “100” (see Figure 135; 8x magnification) on the right lower corner and bell in the inkwell on the right shoulder of the portrait (see Figure 136; 8x magnification), 3-D security ribbon (see Figure 137; 6.5x magnification), protection against copying (see Figure 138; 25x magnification), as the $5, the $10, the $20 and the 50$ banknote and raised ink (see Figure 139; 6.5 x magnification).

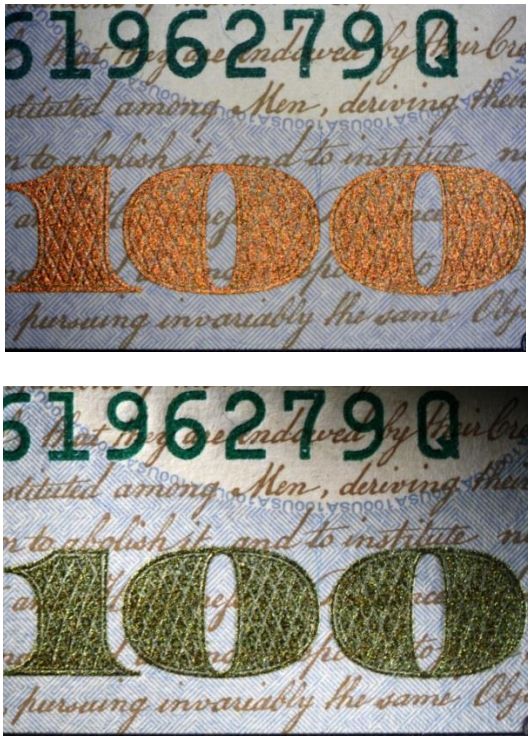


Fig. 135: 100' value view at the right and an accurate angle

Fig. 136: Bell in the inkwell – view at the right and an accurate angle

Fig. 137: 3-D security ribbon (tilted)

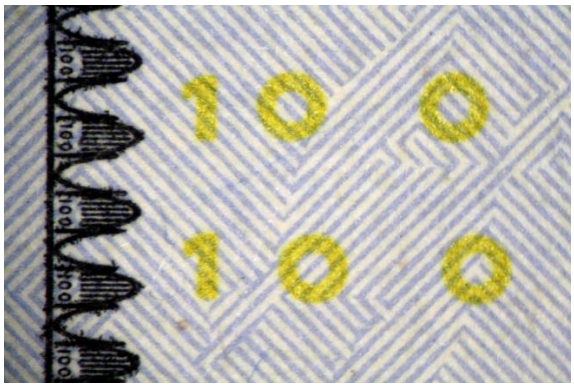
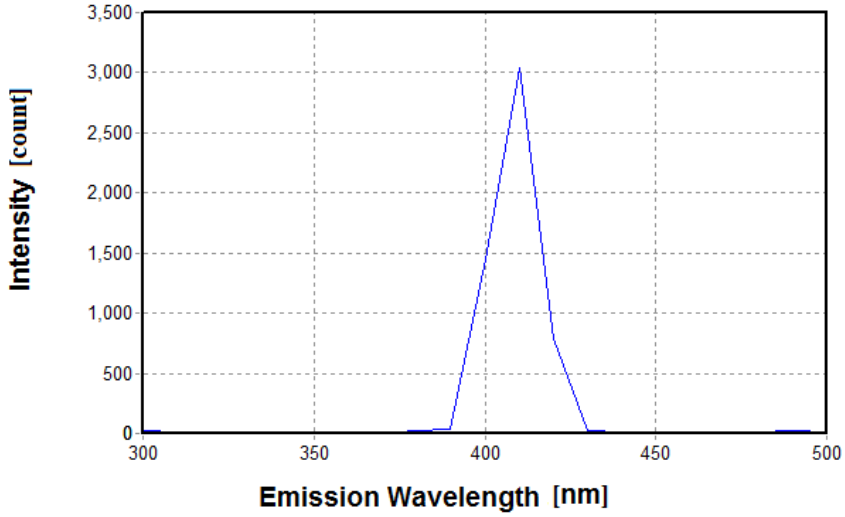
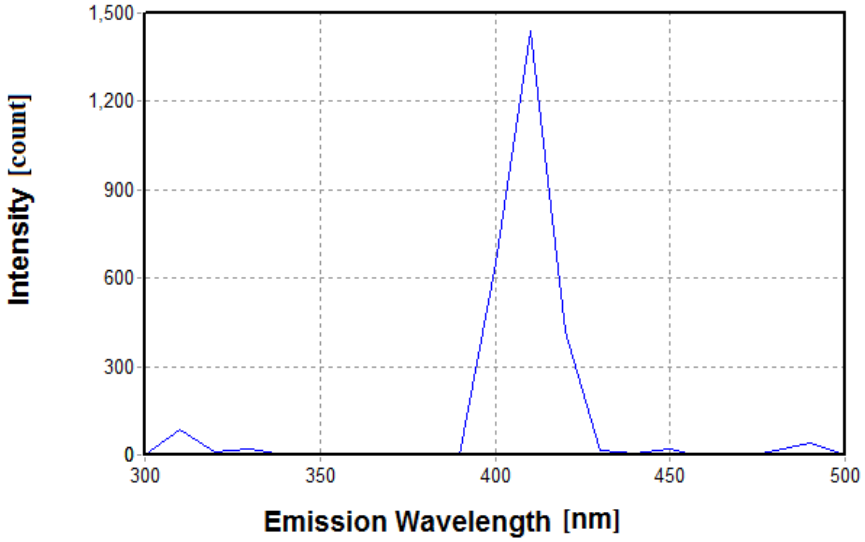


Fig. 138: 100 USD feature against copying

Fig. 139: 100 USD raised ink



Graph 14: 100 USD paper substrate



Graph 15: 100 USD security thread

As Graph 14 and Graph 15 show, the luminescence spectrums are almost the same with the peak around 410 nm. On the other hand the luminescence intensity of paper substrate is stronger in Graph 14 (paper substrate). This fact is very strange because security thread evinced much stronger luminescence (on 254 nm wavelength) than paper substrate. This fact may be caused by measurement errors such as too large an amount of excitation energy (excitation beam), an angle of incident beam that goes to the evaluation unit of spectroflurometer and other.

8.8 Summary of American Dollar

Security thread that contains all U.S. banknotes, from the new $5 banknote and above, is clearly visible when irradiated by 254 nm from the front and back side except the $100

where the security thread is more visible from the back side. Security thread evinced stronger luminescence than the background of banknotes. Despite of this fact, luminescence spectrums that were measured are more different than was expected.

The luminescence intensity of paper substrate of the $1 banknote (1995) is weaker than luminescence intensity of the newer $1 banknote (2013). This fact may be caused by dirt from circulation or different quality of paper substrate of the new banknote. The measured luminescence spectrums correspond with recorded photos when irradiated by 254 nm – paper substrate of the new banknote evinces stronger luminescence than old banknote. The luminescence intensity is weaker on ink area than on paper substrate.

The luminescence intensity of paper substrate of the $2 banknote is weaker than ink area. This fact does not corresponds with measured data on the $1 banknote, neither the 5$ banknote. It may be caused by errors of the measurement process.

The luminescence intensity of paper substrate of the $5 (1988) is much stronger than luminescence intensity of the newer $5 banknote (2013). This fact may be caused by wearing out of the old banknote due to circulation (human sweat and oily secretion, and other liquids). The luminescence intensity of ink area has the weaker luminescent intensity than the paper substrate (on both $5 banknotes) which corresponds with measured data on the $1 banknote.

Except the $20 banknote, where the luminescence intensity of the security thread was approximately about 2 000 counts stronger than luminescence intensity of paper substrate (as corresponds to photos that were recorded in ultraviolet spectrum range) all measured security threads on U.S. banknotes have the weaker luminescence intensity than its paper substrate. This fact may be caused by errors of measuring process, including an amount of excitation energy (excitation beam), an angle of incident beam that goes to the evaluation unit of spectroflurometer, a shutter of the spectrofluorometer (regulate the amount of excitation beam that is hitting to banknote) and other (undetected).

9 CANADIAN DOLLAR

This chapter contains Canadian dollar analysis including photos on banknotes and outputs from the spectrofluorometer with mentioned conditions (Chapter 7). As it mentioned previously, all security features on the Canadian banknotes are the same and therefore they are described only on the one banknote – on the $5 banknote. This denomination was chosen because of the old $5 banknote being available for comparison (still paper banknote). Since 2011 all paper-cotton banknotes were replaced by polymer banknotes (whose advantages are described in Chapter 3.1.2). On the other hand paper-cotton banknote may be still in circulation.

Canadian polymer banknotes do not contain any security features with luminophores but they have been recorded to thesis too.

9.1 5 CAD

The $5 old emission (2006) and the $5 new emission (2013) were examined. Only the old banknote (paper-cotton) contains security features with luminophores.

Fig. 140: 5 CAD 2006/ 2013 on daylight

Fig. 141: 5 CAD 2006/ 2013 when passing daylight

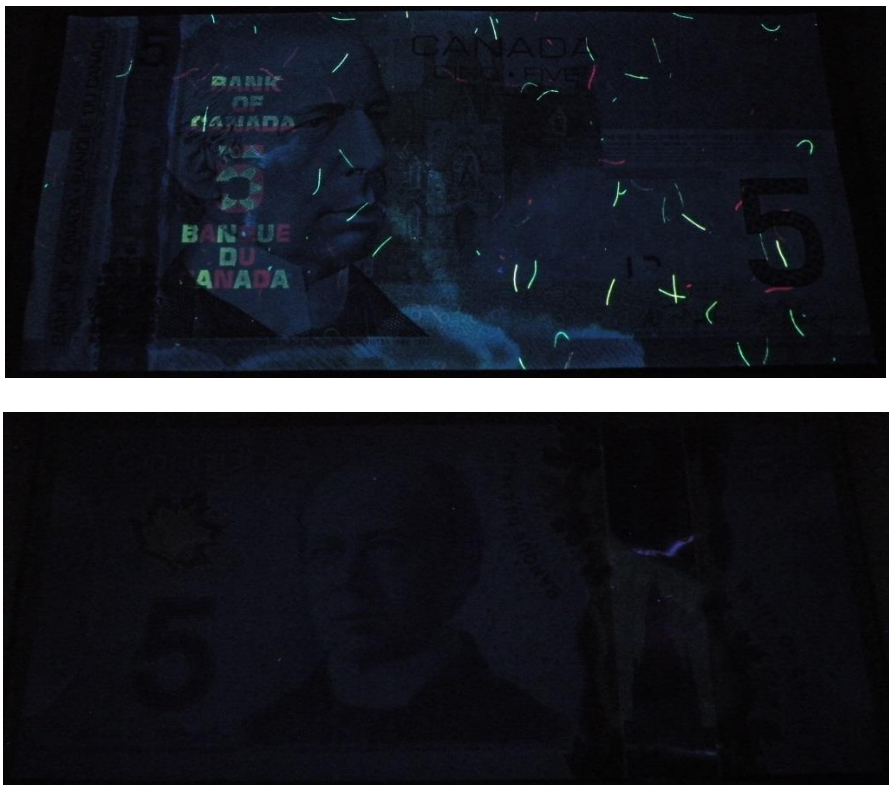


Fig. 142: 5 CAD 2006/ 2013 irradiated by 254 nm

Fig. 143: 5 CAD 2006/ 2013 irradiated by 366 nm

As it can be seen in Figure 140, the newer polymer banknote is completely redesigned. The old $5 banknote contains security features with luminophores that are clearly visible when irradiated by 254 nm wavelength but they are visible when irradiated by 366 nm wavelength as well. On the other hand the newer $5 banknote (polymer) does not have any security features with luminophores at all. There is only a small light reflection on the transparent window which is causes by ultraviolet light reflection from the UV lamp.

In Figure 144 it can be seen the security thread on the old $5 banknote where every photo is illuminated from different position (6.5x magnification). In Figures 145 – 147, there are security fibers without luminophores (Figure 145; 50x magnification) and with luminophores (Figure 146; 40x magnification and Figure 147; 50x magnification). Security fiber without luminophores is visible by human eye but fibers with luminophores are clearly visible only with appropriate magnification (‘red’ luminescent/ colorless fiber is almost invisible even with appropriate magnification, see Figure 147).

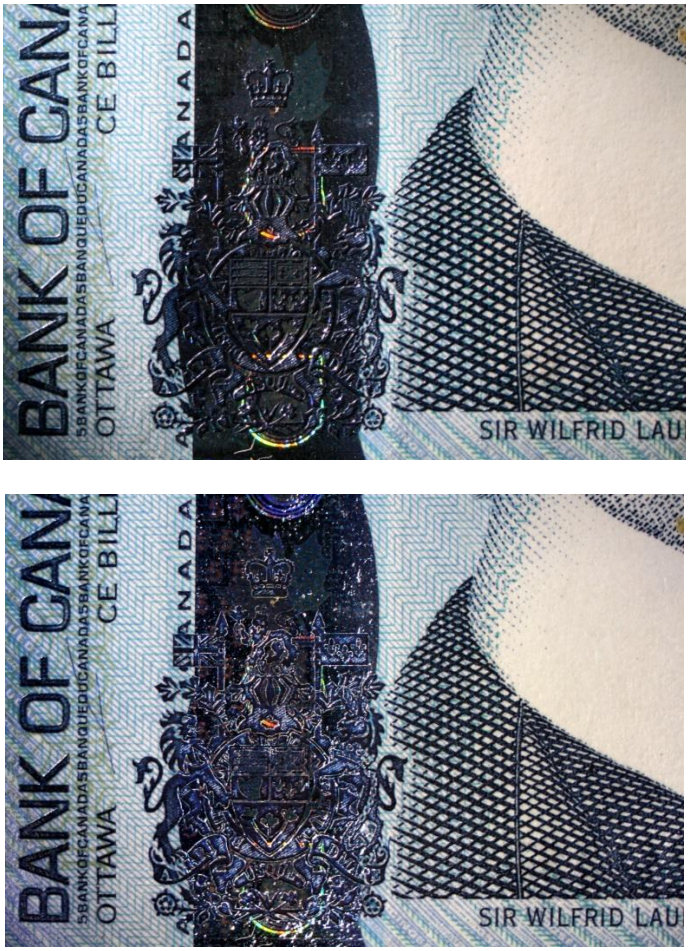


Fig. 144: 5 CAD (2006) security thread

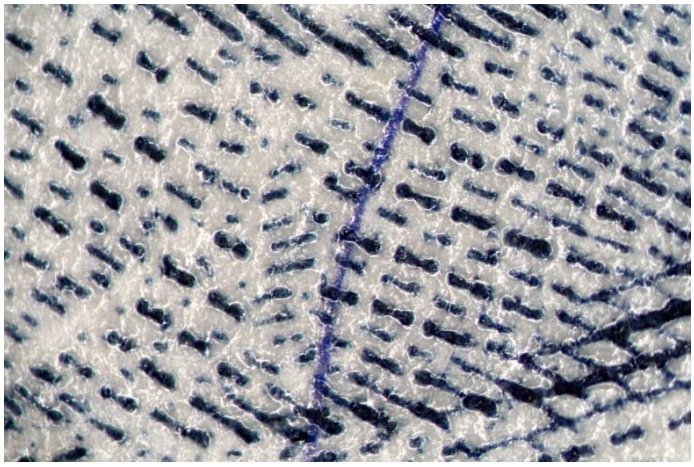


Fig. 145: 5 CAD (2006) non luminescent security fiber

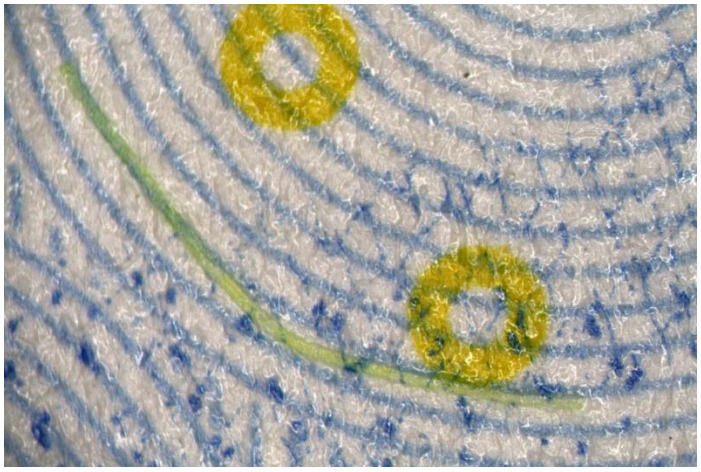


Fig. 146: 5 CAD (2006) 'green' luminescent security fiber

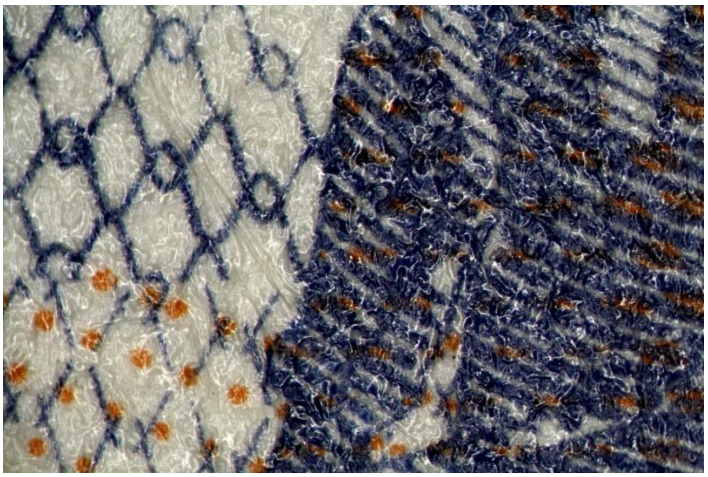


Fig. 147: 5 CAD (2006) 'red' luminescent security fiber

In Figures 148 – 153(except) it can be seen security features mainly in the transparent window. These features together with raised ink and transparent features are the key security features of Canadian polymer banknotes. Figures 154 – 156 represent other security features that are as important as previously mentioned features.

In Figure 148, there is the metallic portrait that is illuminated by side and direct external light source. The color shift may be seen very clearly. The magnification of photos is 6.5x.

In Figure 149 and Figure 150, there is denomination '5' (top of the metallic building) and metallic building that is illuminated by side and direct external light source. The color shifting may be seen very clearly. The magnification of photos is 10x.

In Figure 151 may be seen border between transparent feature (Frosted Maple Leaf) and polymer substrate of banknote. The transition from light to darker area is clearly visible. The magnification of the photo is 25x.

In Figure 152 and Figure 153 may be seen the transparent window with ‘5’ denomination. It is clearly visible that the ‘5’ denomination is pressured onto polymer substrate during manufacturing process. The magnification of photos is 25x and 50x.

Figure 154 and Figure 155 represents raised ink that is one of the key features of genuine banknote. It can be felt when touching the shoulder of the portrait. Addition, in Figure 155 may be seen EURion constellation that is used against copying. The magnification of the photos is 50x

Figure 156 represents Braille that is very helpful for blind people. The magnification of the photo is 16x.

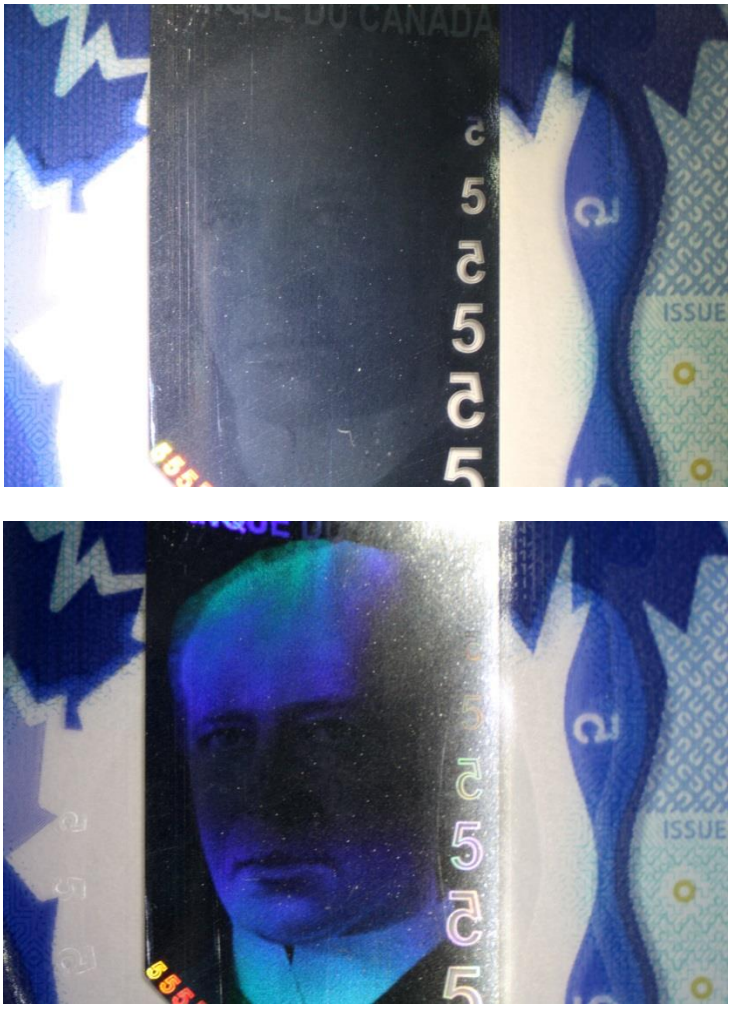


Fig. 148: 5 CAD (2013) metallic portrait

Fig. 149: 5 CAD (2013) '5' denomination

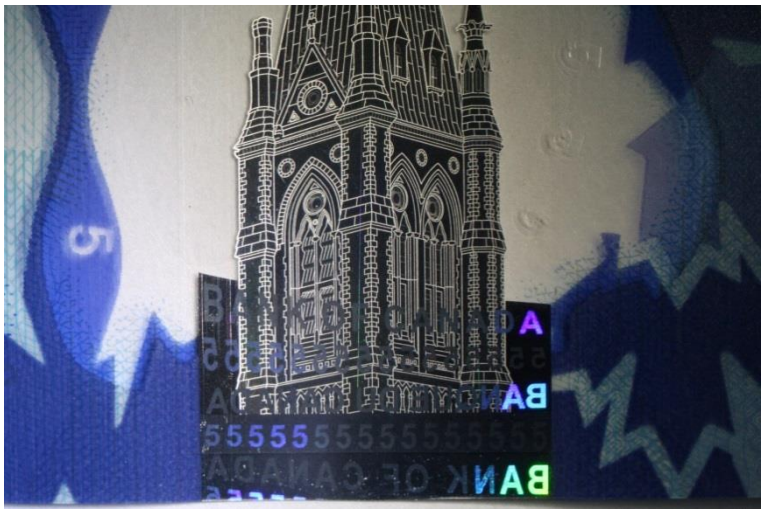


Fig. 150: 5 CAD (2013) metallic building

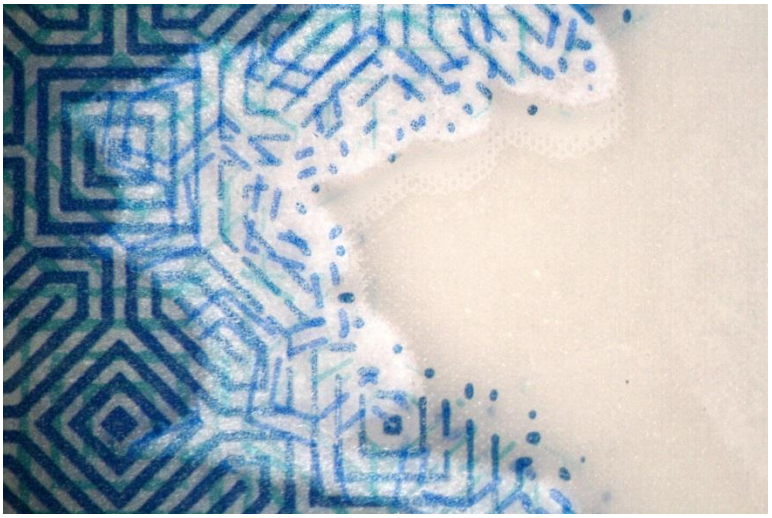


Fig. 151: 5 CAD (2013) border between transparent feature and banknote substrate

Fig. 152: 5 CAD (2013) '5' denomination in transparent window

Fig. 153: 5 CAD (2013) '5' denomination in the polymer substrate

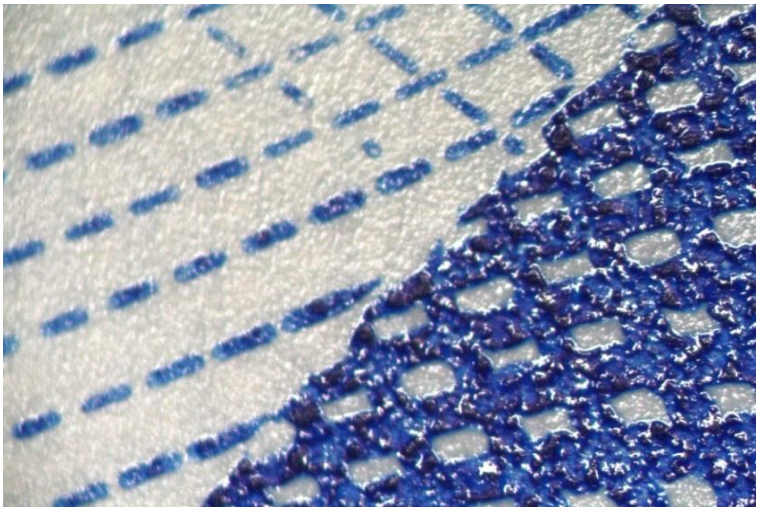
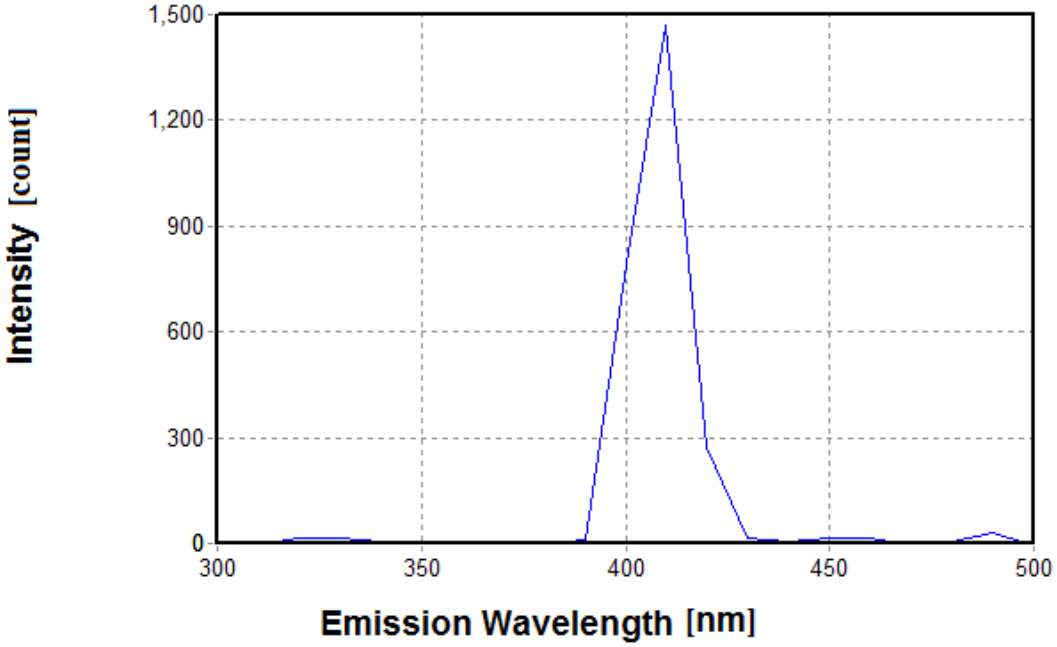


Fig. 154: 5 CAD (2013) raised ink

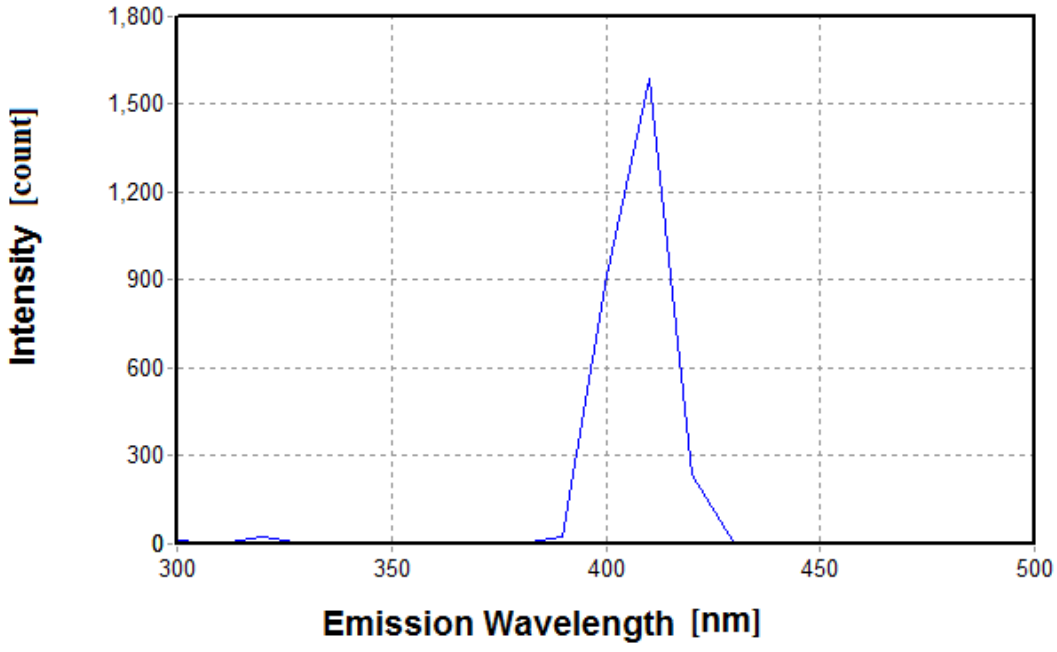
Fig. 155: 5 CAD (2013) feature against copying and raised ink

Fig. 156: 5 CAD (2013) Braille

All mentioned key security features are the same for all Canadian polymer banknotes regardless denomination, as was mentioned before.



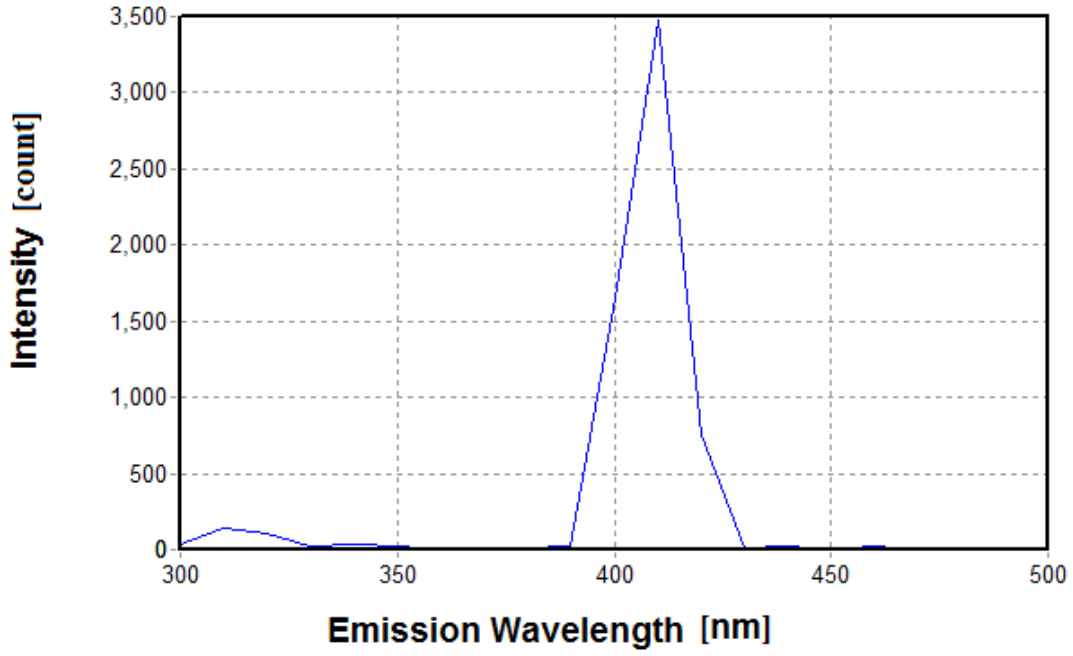
Graph 16: 5 CAD (2006) paper substrate



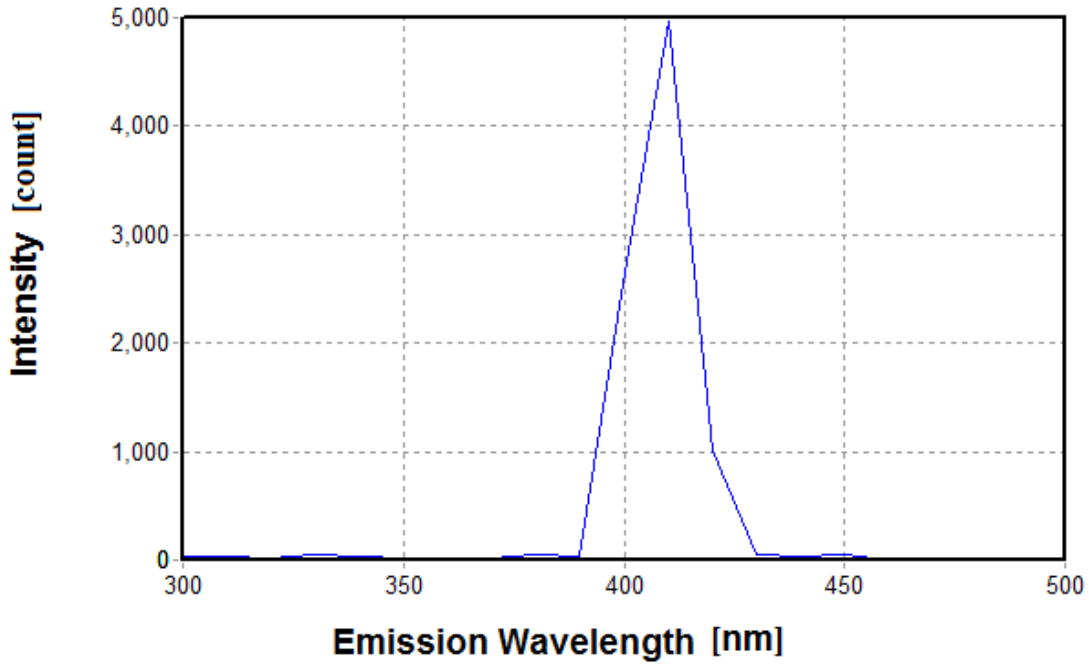
Graph 17: 5 CAD (2013) polymer substrate

Graph 16 and Graph 17 represents luminescence spectrum of the paper and polymer substrate of the $5 banknote. The luminescence spectrum is almost the same in both cases but luminescence intensity of the polymer substrate is a little bit stronger than luminescence intensity of paper substrate. This difference is only several counts. On the other hand this

fact is strange because the polymer substrate does not evince any luminescence. This may be causes by some undetected measurement errors.



Graph 18: 5 CAD (2006) luminescence fiber (red/ colorless)



Graph 19: 5 CAD (2006) luminescence fiber (green)

As it can be seen in Graph 18 and Graph 19, the luminescence spectrums are very similar in both cases but luminescence intensity of red/ colorless luminescence fiber is about 1 500 counts) weaker than luminescence intensity of green luminescence fiber. This fact is

caused by higher luminescence intensity of green security fiber when irradiated by 254 nm (see Figure 142).

9.2 10 CAD

The $10 new emission – from 2013 was examined.

Fig. 157: 10 CAD on daylight

Fig. 158: 10 CAD when passing daylight

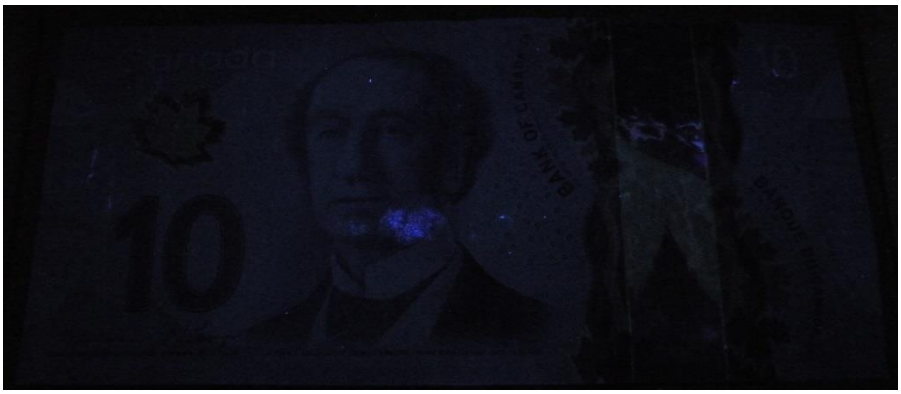
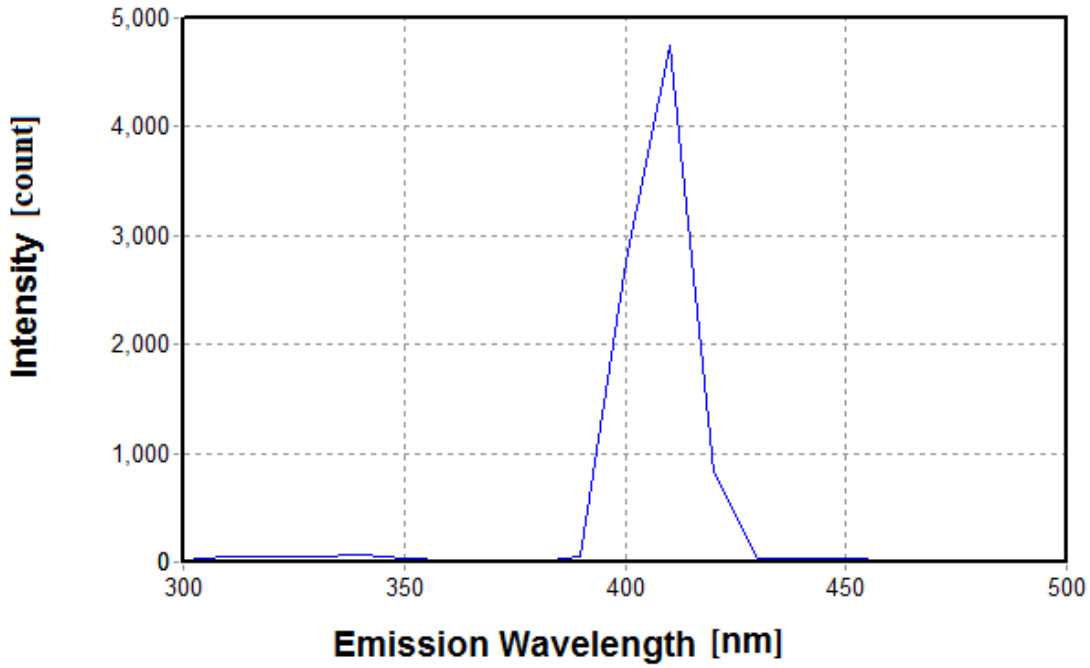


Fig. 159: 10 CAD irradiated by 254 nm

Fig. 160: 10 CAD irradiated by 366 nm

As Figure 159 and Figure 160 show, the $10 banknote does not evince any luminescence (neither from back side of banknote, as all Canadian polymer banknotes). There is only a kind of dirt gained from circulation in the middle of the portrait that luminescent (Figure 159). The illumination on the transparent window, especially on the metallic portrait (in Figure 159 and Figure 160) is caused by ultraviolet light reflection from the UV lamp.



Graph 20: 10 CAD polymer substrate

As it can be seen in Graph 20, the luminescence spectrum of the $10 banknote is very similar as the spectrum of the old $5 and the new $5. But the luminescence intensity is stronger on the $10 banknote more than two times. As the polymer banknotes are more resistant, than paper banknotes to any kind of solutions (human sweat and oily secretion) there may

be still some dirt from circulation that makes stronger luminescence than other cases. Addition, the $10 banknote was the most wear-out of the examined banknotes.

9.3 20 CAD

The $20 new emission – from 2012 was examined.

Fig. 161: 20 CAD on daylight

Fig. 162: 20 CAD when passing daylight

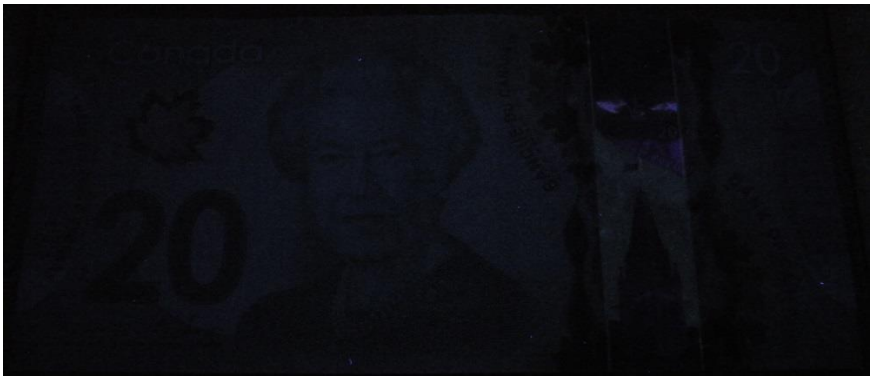
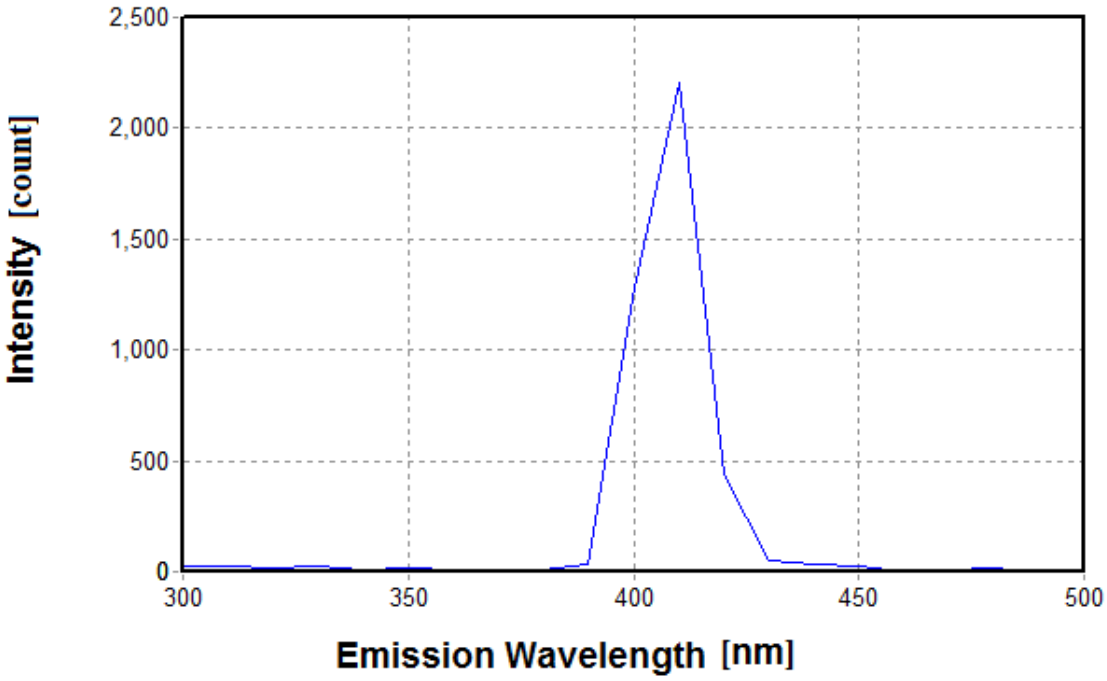


Fig. 163: 20 CAD irradiated by 254 nm

Fig. 164: 20 CAD irradiated by 366 nm

As it can be seen in Figure 163 and Figure 164, the $20 banknote does not evince any luminescence (neither from back side of banknote). The illumination on the transparent window, especially on the metallic portrait (in Figure 163 and Figure 164) is causes by ultraviolet light reflection from the UV lamp.



Graph 21: 20 CAD polymer substrate

Graph 21 represents the luminescence spectrum of the $20 banknote. The spectrum looks very similar to previous luminescence spectrums but the intensity is about 1 000 counts stronger than in the $5 banknote case. On the other hand it is almost two times smaller than on the $10 banknote

9.4 50 CAD

The $50 new emission – from 2012 was examined.

Fig. 165: 50 CAD on daylight

Fig. 166: 50 CAD when passing daylight

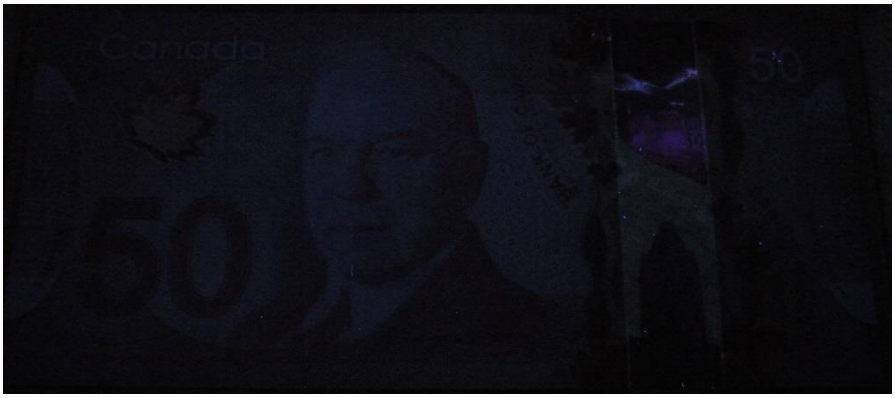


Fig. 167: 50 CAD irradiated by 254 nm

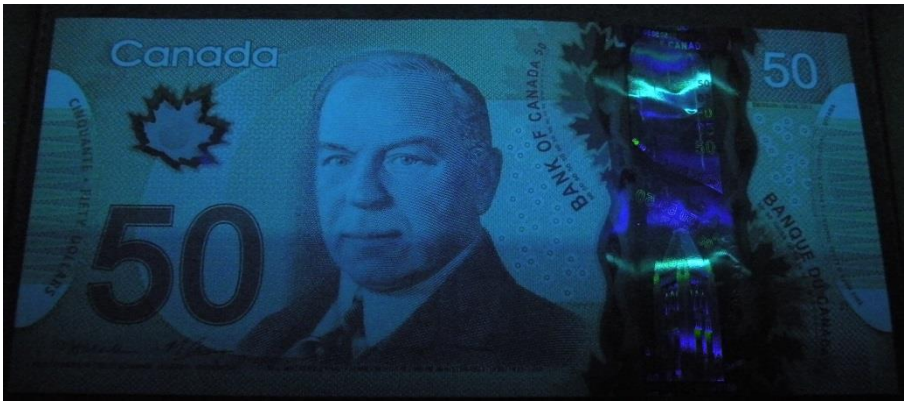
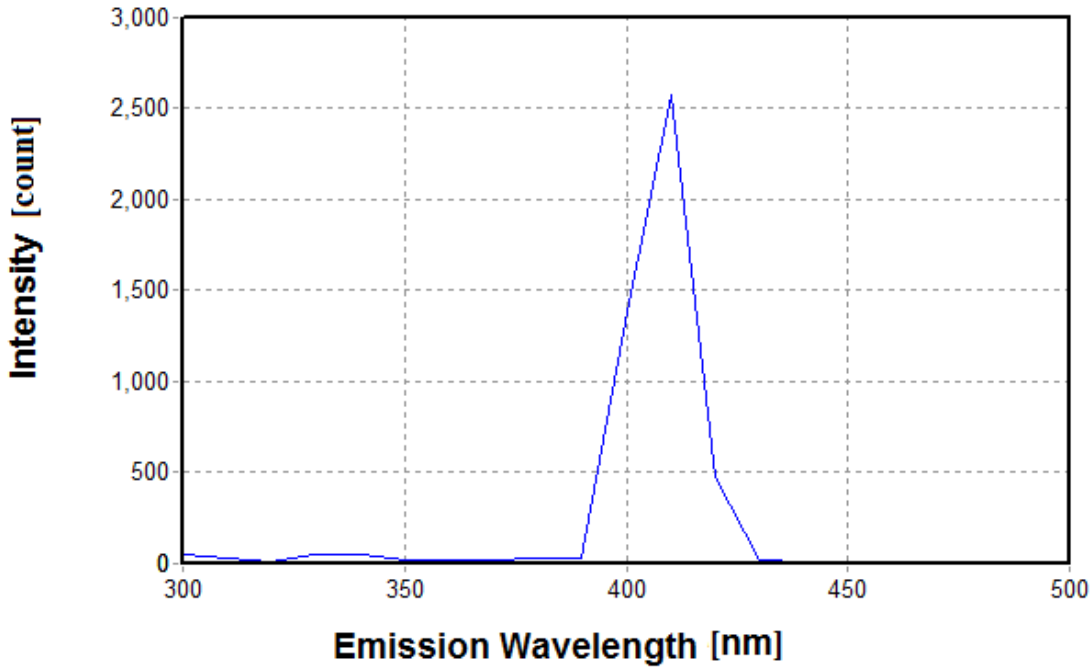


Fig. 168: 50 CAD irradiated by 366 nm

Figure 167 and Figure 168 show that the $50 banknote does not evince any luminescence (neither from back side of banknote). The illumination on transparent window, especially on the metallic portrait (in Figure 167 and Figure 168) is caused by ultraviolet light reflection of the UV lamp.



Graph 22: 50 CAD polymer substrate

Graph 22 represents the luminescence spectrum of the $50 banknote. As it can be seen, the spectrum is almost the same like luminescence spectrum in the previous cases. The intensity of luminescence is about 400 counts stronger than in the $20 banknote case.

9.5 100 CAD

The $100 new emission – from 2011 was examined.

Fig. 169: 100 CAD on daylight

Fig. 170: 100 CAD when passing daylight

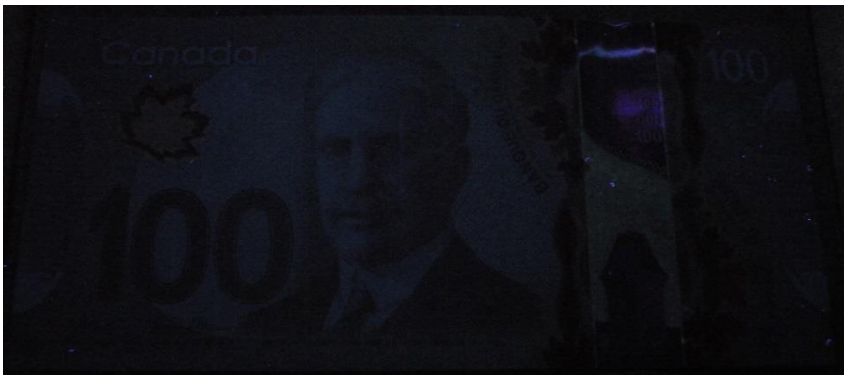


Fig. 171: 100 CAD irradiated by 254 nm

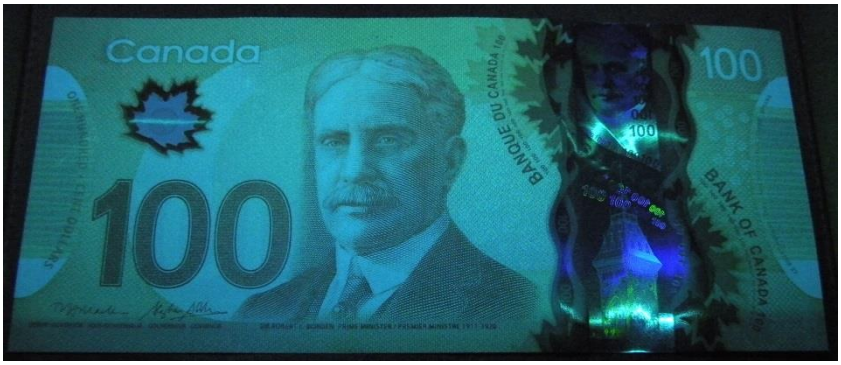
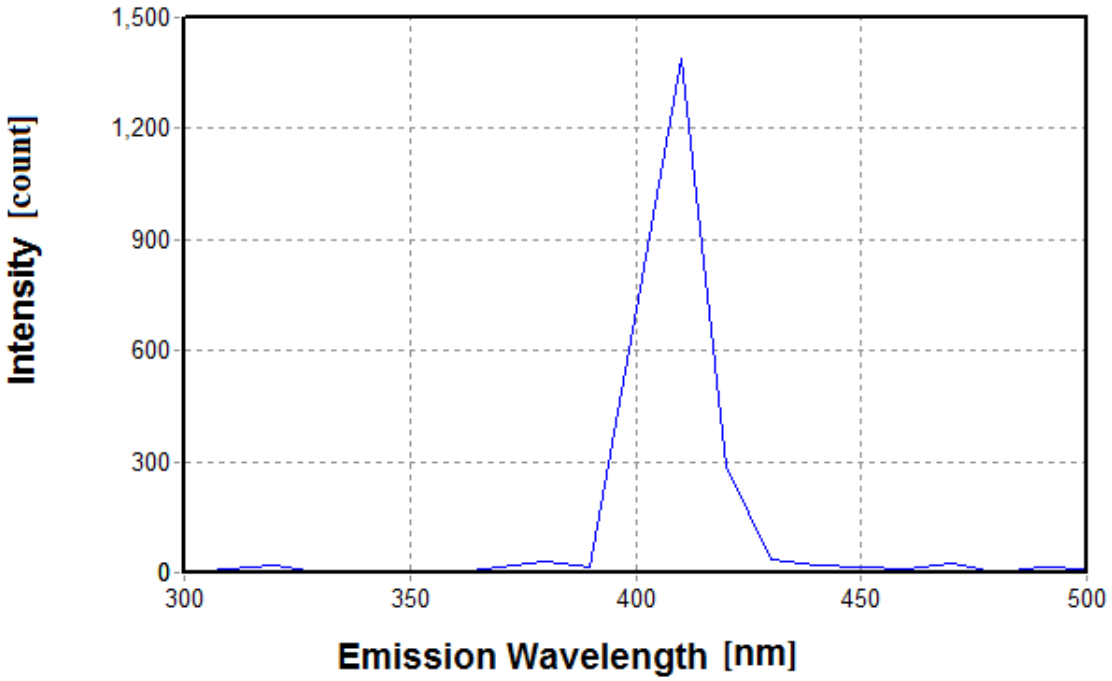


Fig. 172: 100 CAD irradiated by 366 nm



Graph 23: 100 CAD polymer substrate

As it can be seen in Graph 23, the luminescence spectrum is almost the same as in previous cases but the intensity is different – weaker. The luminescence intensity is about 100 counts weaker than on the $5 banknote.

9.6 Summary of Canadian Dollar

As it was found out, Canadian polymer banknotes when irradiated by UV light did not evinced any luminescence. Despite of this fact, at least luminescence spectrum of the polymer substrate was measured for comparison with other banknotes.

Deeper analysis was made with the $5 banknote where the old $5 banknote based on paper-cotton was available. Comparison involved measurements of paper and polymer substrate and two kinds of luminescent fibers (red/ colorless and green ones). The paper and

polymer substrate have almost the same luminescence spectrum – intensity of polymer substrate is a little but stronger. As it may be seen in Figure 142, the luminescence of banknote substrates looks almost the same. In the fibers case, their luminescence intensity of the green fibers is stronger than that one of the red/ colorless fibers about 1 500 counts. This fact is clearly seen in Figure 142 (where the green fibers evince stronger luminescence than the red/ colorless ones).

The luminescence intensity of the $10 banknote evinces the strongest luminescence intensity from all measured polymer banknotes. This fact may be due to wearing out effect connected from circulation as some kind of dirt causing very strong luminescence may be presence of.

The $20 and the $50 banknotes have almost the same luminescence spectrum, the $50 banknote luminescence being about 400 counts stronger then that one of the $20 banknotes, which may be is almost inconsiderable.

The luminescence spectrum of the $100 banknote is very similar to that one of the $5 (paper as well as polymer) banknote, being only 100 counts weaker intensity.

Finally may be said that all Canadian polymer banknotes have very similar luminescence spectrums. The luminescence peak around 410 nm detected in all cases seems to be a little so it may be considered to be caused by some kind of error in measuring process. This error may be connected e.g. with the amount of excitation energy (excitation beam), the angle of incident beam that goes to the evaluation unit of the spectrofluorometer, the shutter of the spectrofluorometer Such factors may influence to the output spectrum. There may occurred other errors that were not detected as well.

CONCLUSION

Presented master's thesis deals with description of security features of American and Canadian dollar and gives general information about these banknotes as far as their history, history of their counterfeiting, printing methods and security features are concerned. The principle of luminescence/ luminescence spectroscopy method that is closely related with security features of banknotes containing luminophores is briefly described.

American old and new banknotes were examined. But only the old $1 and $5 banknote were available. Newer banknotes were redesigned and they got new security features. The luminescence measurement was concentrated on security thread (the $5 banknote and above) that evinced stronger luminescence compared to their paper-cotton substrate. Security thread luminescence spectrum as well as that one of paper-cotton substrate was measured on every banknote. It was expected, the security thread should evince stronger luminescence than the paper-cotton substrate. But this is true only on the $20 banknote. On other banknotes their security threads evinced weaker luminescence than banknote substrate.

As the new Canadian banknotes are based on polymer substrate and are redesigned as well, they do not evince any luminescence within ultraviolet electromagnetic spectrum. This fact was found out when banknotes were irradiated by ultraviolet light (of 254 nm and 366 nm wavelength). For comparison, the old $5 paper-cotton banknote that was available comprising luminescent security features (security fibers with luminophores) was examined. The luminescence intensity of security fibers was found out stronger than luminescence of banknote substrate (paper-cotton and polymer) as it seems rationally luminescence.

Luminescence spectrums of American as well as Canadian banknotes under investigation have the same course. The luminescent peak lies about 410 nm and only the peak intensity is different. It may be said that finals outputs look very similar which may seem strange. Conditions of the measuring process, such as an amount of excitation energy (excitation beam which affects the final luminescence intensity), an angle of incident beam into the evaluation unit of the spectrofluorometer (affects the amount of reflected beam), a shutter of the spectrofluofometer (affects an amount of excitation beam that hitting to the measured banknote too) and the inappropriate calibration of the spectrofluorometer may play certain role. All these aspects may have influence to the final output of the measurement equipment. For this reason I believe the spectrofluorometric analysis itself is not fully

provable tool for detecting banknotes counterfeits and its combination with several other methods is to be recommended.

The most of counterfeited banknotes are not completely perfect. The easiest and the fastest detection of counterfeits are human eyes and touch, and UV lamp provides an additional and fast means of counterfeits detection as well. But even UV lamp cannot be used on banknotes that do not have any luminescent security features (e.g. Canadian dollar). In this case remains to use human eyes or hands (to feel the banknote). Also stereomicroscope is very helpful in detail investigation of banknote substrate and security features but it calls for a good laboratory background. Thus spectrofluorometric analysis, although no fully provable tool for counterfeit detection, provides valuable additional method for solving banknotes counterfeit problems.

BIBLIOGRAPHY

[1] *How Was Money Born?* [online]. [cit. 2016-01-20]. Available from: http://oko.yin.cz/29/jak-se-zrodily-penize/

[2] PEKÁREK, Jiří. *Can you detect a counterfeited banknote?* 1st ed. Prague: Pragoeduca, 2000, 78 p. ISBN 80-85856-84-0.

[3] Bank Charges: History of Money in the Middle Age. [online]. 2005 [cit. 2016-01-20]. Available from: http://www.bankovnipoplatky.com/historie-penez-ve-stredoveku-bankovnictvi-16122005-131.html

[4] Records. The Oldest Banknote [online]. [cit. 2016-01-20]. Available from: http://www.rekordy.org/vyhledavani.php?fulltext=id&hledej=59

[5] Great Historical Counterfeits. Psb.org [online]. [cit. 2016-01-20]. Available from: http://www.pbs.org/opb/historydetectives/feature/great-historical-counterfeits/

[6] Valuable Metals in the Middle Age: How was cleaned, counterfeited and detected. Science World [online]. 2013 [cit. 2016-01-20]. Available from: http://www.scienceworld.cz/neziva-priroda/drahe-kovy-ve-staroveku-jak-se cistilo-falsovalo-a-odhalovalo-778/

[7] TRUKHACHEV, B a M. B. SERGEYEV. *Technology for Protection Banknotes and Securities. St. Petersburg*, 2012, 110 p. ISBN 978-5-8088-0780-8.

[8] Innovia Security. *Guardian® - Facts and Figures* [online]. Australia: Innovia Security, 2015 [cit. 2016-03-03]. Available from: https://www.innoviasecurity.com

[9] Giesecke & Devrient GmbH. *Hybrid* [online]. Louisenthal, 2009, **2009**(11), 4 [cit. 2016-03-03]. Available from: http://www.gi-de.com/gd_media/media/en/documents/brochures/paper/Hybrid.pdf

[10] SIEGEL, Jay A and Pekka SAUKKO (eds.). *Encyclopedia of forensic sciences*. 2nd ed. Amsterdam: Elsevier, c2013. ISBN 978-0-12-398365-7.

[11] Regula. *Glossary of Banknotes* [online]. 2008 [cit. 2016-03-03]. Available from: http://www.regulaforensics.com

[12] DOLEŽAL, Ivan. Security Features of Czech Banknotes. The World of Press. [online]. 2004 [cit. 2016-01-17]. Available from http://www.svettisku.cz/buxus/generate_page.php?page_id=3693&buxus_ svetti-sku=182c0350ebd9a3430bf80d9aa9981cb9

[13] Council of the EU. *Prado Glossary* [online]. 2007 - 2015, 138 [cit. 2016-03-03]. Available from: http://www.consilium.europa.eu/prado/cs/prado-glossary/prado-glossary.pdf

[14] RFID banknotes. Fleur-de-coin [online]. [cit. 2016-01-20]. Available from: http://www.fleur-de-coin.com/eurocoins/banknote-rfid

[15] Security Threads. *Giesecke & Devrient GmbH* [online]. Munich [cit. 2016-03-03]. Available from: http://www.gi-de.com

[16] *U.S. Currency Education Program* [online]. Washington, D.C.: U.S. Government [cit. 2016-03-03]. Available from: https://uscurrency.gov/

[17] Colonial Williamsburg. *The Golden Age of Counterfeiting* [online]. Trend & Tradition, 2007 [cit. 2016-03-03]. Available from: http://www.history.org/index.cfm

[18] Uneasy Money. *Counterfeiting and American Monetary History* [online]. Hawtrey, 2012 [cit. 2016-03-03]. Available from: https://uneasymoney.com/

[19] GQ. *The Great Paper Caper* [online]. 2014 [cit. 2016-03-03]. Available from: http://www.gq.com

[20] *BUREAU OF ENGRAVING AND PRINTING U.S. Department of the Treasury* [online]. Washington, D.C.: U.S. Department of the Treasury [cit. 2016-03-03]. Available from: http://www.moneyfactory.gov/uscurrency/howmoneyismade.html

[21] Uneasy Money. *Counterfeiting and American Monetary History* [online]. Hawtrey, 2012 [cit. 2016-03-03]. Available from: https://uneasymoney.com/

[22] *MindSerpent: The Face of U.S. Currency* [online]. 2010 [cit. 2016-03-03]. Available from: http://www.mindserpent.com/American_History/federal/fed_res/publications/minneapolis/01_pictures.htm

[23] *KTRS: Fed moves to bar bailouts of failing firms* [online]. 2015 [cit. 2016-03-03]. Available from: http://www.ktrs.com/fed-moves-to-bar-bailouts-of-failing-firms/

[24] *ZeroHedge: The US Does Not Own Or Control Its Money System* [online]. 2010 [cit. 2016-03-03]. Available from: http://www.zerohedge.com/article/us-does-not-own-or-control-its-money-system

[25] *Gizmodo: Here's The New And Improved Hundred Dollar US Bil* [online]. 2013 [cit. 2016-03-03]. Available from: http://www.gizmodo.com.au/2013/04/heres-the-new-and-improved-hundred-dollar-us-bill/

[26] *The Banknote Den: U.S.A. Banknotes Major Designs of United States Currency* [online]. [cit. 2016-03-03]. Available from: http://www.banknoteden.com/USA.html

[27] *Boingboing: New US$100 bill in circulation 10/8* [online]. 2013 [cit. 2016-03-03]. Available from: http://boingboing.net/2013/04/24/new-us100-bill-in-circulation.html

[28] *Currencies of the World: 50 US Dollars, Series NEXGEN* [online]. [cit. 2016-03-03]. Available from: http://demo.icpress.ru/en/demo/countries/242/single_banknote/11670.html

[29] POWELL, James. *A History of the Canadian Dollar*. Ottawa: Bank of Canada, 2005. ISBN 0-660-19571-2.

[30] *The Royal Canadian Mounted Police: Counterfeit Currency in Canada* [online]. The Royal Canadian Mounted Police, 2007 [cit. 2016-03-03]. Available from: http://www.rcmp-grc.gc.ca/pubs/ci-rc/cf/index-eng.htm#tech

[31] *The Global and Mail: Release Shows How to Spot a Fake Hundred* [online]. New Westminste, British Columbia: New Westminster Police Department, 2007 [cit. 2016-03-03]. Available from: http://www.theglobeandmail.com/news/british-columbia/article11965668.ece/BINARY/RCMP+release+shows+how+to+spot+a+fake+hundred.pdf

[32] *Bank of Canada: Principles for Bank Note Design* [online]. [cit. 2016-03-03]. Available from: http://www.bankofcanada.ca/banknotes/principles-bank-note-design/

[33] *Bank of Canada: Security Features* [online]. [cit. 2016-03-03]. Available from: http://www.bankofcanada.ca/banknotes/bank-note-series/polymer/security-features/

[34] *Currencies of the World: 50 Canadian Dollars, Series of 2011-2013* [online]. [cit. 2016-03-03]. Available from: http://demo.icpress.ru/en/demo/countries/47/single_banknote/11754.html

[35] PE AMERICAS a TRYSKELE. *Life Cycle Assessment of Canada's Polymer Bank Notes an d Cotton-Paper Bank Notes* [online]. 2011, 117 [cit. 2016-03-03]. Available from: http://www.bankofcanada.ca/wp-content/uploads/2011/06/Life-Cycle-Assessment-of-Polymer-and-Cotton-Paper-Bank-Notes_opt.pdf

[36] PELANT, Ivan a Jan VALENTA. Luminescence spectroscopy of semiconductors. 1st pub. New York: Oxford University Press, 2012, xiv, 542 s. ISBN 978-0-19-958833-6.

[37] Luminescence Analysis. Kpufo [online]. 1982. vyd. [cit. 2016-01-17]. Available from: http://www.kpufo.cz/oblasti/oso/patrov/c_lum.htm

[38] CHIA, Thomas a Michael LEVENE. *Detection of counterfeit U.S. paper money using intrinsic fluorescence lifetime*. Portal.k.utb [online]. Optics Express, 2009, no. 24 [cit.2014-01-20]. ISSN:1094-4087. Available from: http://portal.k.utb.cz/articles/record?id=FETCH-LOGICAL-e851-6a7b7f1ace940f1d8dd8ac984366949dc06223f4a63fd17cc15b3fec0a5a9c381

[39] HAWKES, P a John C SPENCE. Science of microscopy. 1. New York: Springer, 2007, 2 v. (xviii, 1265, I26 p.). ISBN 03-872-5296-7.

LIST OF ABBREVIATIONS

UV Ultraviolet.

IR Infrared.

RFID Radio Frequency Identification.

LIST OF FIGURES

LIST OF TABLES

LIST OF GRAPHS