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THE POSSIBILITIES OF PRINTED ELECTRONICS FOR MAKING BANKNOTES' ANTI-COUNTERFEITING FEATURES ACTIVE

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Напрямками створення активних захисних елементів є застосування в банкнотах хімічних сенсорів, електронної основи, «розумних» наноматеріалів та тактильно активних п'єзоелектричних елементів. Зокрема, це можливо реалізувати, застосовуючи можливості друкованої електроніки. В статті проаналізовано можливості, а також ймовірні проблеми застосування друкованої електроніки для створення активних захисних елементів банкнот. Створення на банкнотах схем на органічних напівпровідниках може бути надзвичайно корисним доповненням до традиційних технологій, що надає можливість отримати банкноти з активним захистом від несанкціонованого копіювання.

Направлениями создания активных защитных элементов являются применение в банкнотах химических сенсоров, электронной основы, «умных» наноматериалов и тактильно активных пьезоэлементов. В частности, это можно реализовать, применяя возможности печатной электроники. В статье проанализированы возможности и вероятные проблемы применения печатной электроники для создания активных защитных элементов банкнот. Создание на банкнотах схем на органических полупроводниках может быть чрезвычайно полезным дополнением к традиционным технологиям, которое дает возможность получить банкноты с активной защитой от несанкционированного копирования.

I. Introduction

Banknotes producers use numerous different anti-counterfeiting features, such as intaglio printing, watermarks, optically variable inks, security threads, microprinting, micro-perforation, transparent windows, rainbow printing, fluorescent fibers, and inks with ultraviolet or infrared properties, so on [1]. The common feature of them is being passive. The researchers try to create active anti-counterfeiting features for banknotes by different means. One of the ways to make banknote security features active is to use the possibilities of printed electronics.

II. The ways to make banknotes' protection active

There are several research directions for making active anti-counterfeiting features. They are chemical sensors, e-substrate, smart nanomaterials, and tactilely active piezoelectric features. The security feature must have two main characteristics: it deters (or prevents) reproduction and it facilitates authentication. While many transactions take place in a venue in which unassisted human authentication is preferred or only option an increasing number of transactions involve alternative assisted methods [2].

A. Chemical Sensors

Chemical sensors are sensors embedded in a banknote that detect chemicals generated either by direct human interaction or from test system and produce human perceptible signal. The detected chemicals can be different [3]. Passive sensors change their appearance directly. Active sensors can trigger visual, audible, or tactile responses.

B. Smart Nanomaterials

Nanomaterials and nanotechnologies have already become the part of banknote production. The directions of their implementation are surface and volume impregnation for banknote paper durability [4], nanoprinting (for example, printed sun pattern composed of 60-nm-diameter Au particles [5]), different diffractive nanostructures (diffractive optically variable image devices, interference security image structures, zero order devices, diffractive identification devices, diffractive watermarks [6]), nanoperforated substrates [7], nanocrystal pigments [7]. All mentioned above nanomaterials and nanotechnologies are passive.

The term «smart» nanomaterial we use for nanomaterials exhibiting a wide range of dynamic behaviors [4]. So, for banknotes security features can be used polymeric nanocomposite microactuators driven by programmable heterogeneous magnetic anisotropy [9]. As result polymeric microactuators can undergo predesigned, comlex two- and three-dimensional motion that means human visible response.

C. Tactilely Active Piezo-electric Features

The piezoelectric effect may be used in currency applications to generate a detectible change in the tactile feel at a specific location on a banknote. It means that one can envision bumps that raise or lower on the note when a voltage is applied. Patterns of fine bumps could possibly be produced to provide each denomination with unique, readily identifiable pattern [2]. Multimaterial piezoelectric fibers [10] applied for banknotes protection could demonstrate not only tactile, but also visual and audible responses.

D. e-Substrate

The active e-substrate means that patterns that compose the feature are active devices that can respond to a cash handler or a machine reader. Active e-substrate features demand including such elements as power generation, circuitry, and a human perceptible response [2]. Features such as chemical sensors and tactilely active piezoelectric features described before would use active e-substrate technology.

III. The inplementation of e-substrate

Active e-substrates refer to classes of features that are enabled by techniques and materials emerging from developments in large-area and/or low-cost electronics. The problems to be solved for implementation of active e-substrate are forming the electronics components, design of power generating devices for adequate power supply, and the production of human perceptible response.

A. Power-Generating Devices

The power supplying for active e-substrate can be realized by implementation of different devices, such as organic ratchet devices (set-ups composed of periodically arranged units with inherent asymmetry, and can be driven by unbiased, time-dependent, random or deterministic forces [11]), piezoelectric devices (the source of energy is pressing (squeezing) or shaking the banknote, with power-generation capability about 200 µW [12]), reverse Peltier thermoelectric devices (the source of energy is the temperature gradient between cash handler and ambient environment, for example, as result of holding a banknote between fingers, breathing on the banknote, or placing it in warm or cold location [13] with power-generation capability about 100 µW of power and 3 V with 1 °C temperature change on 6 cmI surface [14]), solar cells (the sources of energy are all possible external light sources (sunlight, flame, or electric light [15])). The power supply is possible due to variable capacitors manufactured using traditional MEMS fabrication methods (the source of energy (the source of energy is pressing (squeezing) or shaking the banknote, with power-generation capability about 100 µW per 1 cmi [2]), as well as inductive devices, or high power density batteries [2]. But the letters are needed to reduce size and cost.

B. Human-Perceptible Response

The concept of e-substrate can provide assisted human-perceptible response as well as the visibility of response. The letter can be realized by implementation organic light-emitting-diodes (OLEDs), or inorganic LEDs powered by a MEMS piezoelectric devices activated by shaking. OLEDs can be printed onto any suitable substrate (plastic or paper) by an inkjet printer or even by screen printing. OLEDs can have a rather fast response time (less than 0,01 ms response time, enabling up to 100,000 Hz refresh rate). OLED pixels emit light directly with colours appearing correctly without shifting, even as the viewing angle approaches 90° from normal [16]. The inorganic LEDs have the advantage of avoiding associated with OLEDs. Printing-based assembly methods can deposit these devices on substrates of glass, plastic, or rubber, in arbitrary spatial layouts and over areas that can be much larger than those of the growth wafer. The thin geometries of these LEDs enable them to be interconnected by conventional planar processing techniques. Displays, lighting elements, and related systems formed in this manner can offer interesting mechanical and optical properties [17].

IV. Printed electronics for banknotes

One way for forming the electronics components of an active e-substrate is the deposition and patterning of the circuit layers directly on the substrate (for example, plastic for security strip, or even banknote paper) by means of printed electronics. Other way is incorporation of silicon chip into banknote. Though it was expected to embed radio frequency identification tags (RFIDs) into the very fibers of euro bank notes by 2005 and a chip designed for paper money that would pack RFID in a 0,4-mm square circuit measuring 60 мm thick. [18], this expectation has not been realized, mainly because of significant thickness of silicon wafer. Then it was succeeded to reduce the thickness of silicon chip to 20 мm [19, 20]. It was developed the technique of transferring the thin silicon membranes from a wafer onto plastic substrates and be processed into flexible circuits [21]. Although it may be possible to transfer silicon membranes onto banknote as well, the harsh process conditions during circuit manufacturing may irreversibly damage banknote. The next step of chip incorporation into banknote may be the laminating of electronic systems described in [22] that achieve thicknesses, effective elastic modules, bending stiffness, and mass densities matched to the epidermis. Unlike traditional wafer-based technologies, laminating such devices onto the skin leads to conformal contact and adequate adhesion based on van der Waals interactions alone, in a manner that is mechanically invisible to the user.

The advantages of printed electronics as technology for fabricating of thin-film transistors (TFTs) on foils, fibers, and paper [16–17, 23–27] were described widely. Organic materials has a number of advantages of special importance for printing on paper substrate, i.e. large area coverage, processability in liquid form, low-temperature processing, and structural flexibility [28]. So, one of the first data on printed electronics on paper was [29] where organic TFTs array with field-effect mobility up to 0,086 cmI/V·c and on/off ratio about 10^4 fabricated on flexible paper substrate described. One of the first steps to fabrication of the organic circuit on banknotes made researchers [30]. In this paper the flexible 8 bits organic RFID tag with critical dimension 2 мm demonstrated the data rate of 50 kb/s suitable for electronic products coding was described. But only in 2010 the possibility of the organic circuit fabrication on banknote was implemented in research [31] where arrays of organic transistors and circuits printed on different currency notes (Euro, US-dollar, Japanese-yen, and Swiss-frank) have been presented.

The group of researchers [31] used the method of microcontact printing of self-assembled monolayers [32] as a printing process for electronic devices that combines the concepts of direct and indirect printing in the same printing step and for the same material by employing a transferred pattern both as an etch resist (indirect printing) and as a functional material as part of the final device (direct printing). The transistors and circuits have a thickness of less than 250 nm and operate at a low voltage of 3 V [31]. It was shown that TFT printed on banknote paper can demonstrate the mobility of 0,57 cmI/V·c and on/off ratio about $7 \cdot 10^4$.

V. Main Problems of implementation printed electronics into banknotes

A. Stability

Many organic materials have stability problems in the air due to their interaction with the surrounding environment.

Main disadvantage of OLEDs for implementation into banknote security features is poor water resistance but it can be reduced by application of additional protective layer [16].

Other way of stability increasing has been recently described [33]. The p-type and n-type polymer semiconductors were thermally annealed in ambient conditions after ink-jet printing. The good performance of circuit shows that the transistors are not only air-stable in term of ambient humidity and oxygen, but also inert to ion migration through dielectric from the printed gate. The obtained result has confirmed the feasibility of low-cost polymer circuit in practical environment.

B. Limitation of Nanu-factoring Process

The strong limitations during incorporation of printed circuits onto banknote are determined by changing form of paper surface caused by wetting. To reduce this effect at least for circuit printig as a water and chemical barrier layer, 6-мм-thick parylene has been coated on the paper substrate by using the vacuum deposition [29]. The parylene layer protects the paper substrate from becoming damp during the wet chemical process. But for solving the problem of changing of paper surface because of wetting it is expediently to print organic circuits as post-press stage.

Other limitation is temperature of processes. So, the temperature of annealing in research [33] was 80–140 °C during 30 min. To tell the truth, only low level of such treatment is suitable for banknotes.

C. Paper roghness

The surface topography of banknote paper is one of the main problems [29, 31–33]. We established that the average roughness of banknote paper is 1,5–3,8 мм with extreme roughness up to 20 мм [34]. But in authors' [32] opinion, such roughness is rather long-range waviness for TFTs with thickness about 250 nm. To reduce the surface roughness it is possible to create the coating of paper substrate [29], or prepare the surface using the possibilities of traditional printing, for example, the effect of stamping during intaglio printing.

CONCLUSIONS

The ways to make anti-counterfeiting features active are the incorporation of chemical sensors, e-substrate, smart nanomaterials, and tactilely active piezoelectric features in banknotes.

The active e-substrate means that patterns that compose the feature are active devices that can respond to a cash handler or a machine reader. Features such as chemical sensors and tactilely active piezoelectric features would use active e-substrate technology which is the core of active banknotes' anti-counterfeiting features.

The ways for forming the electronics components of an active e-substrate are incorporation of silicon chip into banknote, or the deposition and patterning of the circuit layers directly on the substrate (for example, plastic for security strip, or even banknote paper) by means of printed electronics.

The implementation of active e-substrate are forming the electronics components, design of power generating devices for adequate power supply, and the production of human perceptible response.

The ability to fabricate organic circuits on banknotes may be the outstanding supplement for traditional security features and create the possibility of outfitting banknotes with active electronic security features.

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