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DEPARTMENT OF THE NAVY
NAVAL UNDERSEA WARFARE CENTER
DIVISION NEWPORT
OFFICE OF COUNSEL
PHONE: 401 832-3653
FAX: 401 832-4432
DSN: 432-3653

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TECHNOLOGY PARTNERSHIP ENTERPRISE OFFICE
NAVAL UNDERSEA WARFARE CENTER
1176 HOWELL ST.
CODE 07TP, BLDG. 990
NEWPORT, RI 02841

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Inventor Thomas Ramotowski

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Attorney Docket No. 99704

ELECTROACTIVE POLYMERS WITH ANTI-COUNTERFEITING FEATURE

STATEMENT OF GOVERNMENT INTEREST

[0001] The invention described herein may be manufactured and used by or for the Government of the United States of America for Governmental purposes without the payment of any royalties thereon or therefor.

CROSS REFERENCE TO OTHER PATENT APPLICATIONS

[0002] None.

BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

[0003] The invention relates to systems and methods for assuring the authenticity of documents in general and particularly to systems and methods that employ an electroactive polymer as a component.

DESCRIPTION OF THE PRIOR ART

[0004] Many systems and methods have been used in attempts to assure the authenticity of documents, including documents representing monetary value such as currency, checks and bonds, documents representing proof of identity such as

passports, identification papers and drivers' licenses, and other valuable or important documents. Systems and methods that have been employed include: the use of watermarks; the use of specially manufactured paper; and specially printed documents using plates prepared using micro-engraving.

[0005] It is well known that paper currency is passed from person to person until the certificate becomes sufficiently worn that it needs to be removed from circulation. Using United States One Dollar certificates as an example, it is common that the time required for such certificates to become sufficiently worn is about one to two years. In addition, paper currency often suffers intended and unintended abuse, including: being sent through vending machines and automated teller machines (ATMs); being written upon; being subjected to washing; being folded; and being crumpled. In order to be useful, any system or method of providing a test of authenticity will have to survive such mistreatment.

[0006] Some prior art systems and methods rely on the presence of security threads. U.S. Patent No. 6,259,506 to Lawandy discloses a security thread system for paper documents that uses dispersed liquid crystals (possibly encapsulated in polymers) which respond to laser or ultraviolet excitation. U.S. Patent No. 7,090,917 to Puttkammer describes the use of security strips comprising conductive polymers.

[0007] Other systems and methods rely on the presence of optical features such as holograms or color changes under varying illumination or viewing angles. Other systems and methods that rely on inclusion of electronic circuits, such as circuits that encode information (such a serial number and denomination) and that can be interrogated using radio frequency methods, have been described.

[0008] United States Patent Application Publication No. 2003/0164611 by Schneider et al. describes a security paper for producing documents of value, such as bank notes, certificates, etc., with at least one multilayer security element having at least one visually checkable optical effect. Schneider et al. employ at least one integrated circuit in one inside layer. This integrated circuit is for example a memory chip (ROM), a rewritable chip (EPROM, EEPROM) or a microprocessor chip. The system also uses a layer containing optically variable pigments (in particular interference-layer or liquid-crystal pigments) to provide the optical effect.

[0009] U.S. Patent Application Publication No. 2008/0220186 by Port et al. describes an optically active film laminate comprising a transparent film substrate which at least in part has been dyed to a dark coloration by dye or dyes applied to one side of the substrate, and a cholesteric (or chiral nematic) liquid crystal coating.

[0010] United States Patent No. 6,918,535 to Brosow (hereinafter "Brosow") describes such an embedded circuit and dipole antenna system fabricated using polymeric materials. Brosow suggests that the encoded information in the embedded circuit can be compared to information that can be observed on the face of the document, with rejection of the document as a forgery in the circumstance where the comparison fails.

[0011] United States Patent No. 4,792,667 to Chen discloses a method and apparatus for authenticating documents utilizing poled pyroelectric or piezoelectric polymeric material that undergo phase changes upon heating to a critical temperature. The documents can be identified as having been tampered with when the polymeric material is depoled.

[0012] United States Patent No. 6,025,200 to Kaish et al. discloses a taggant such as perfluorocarbons for paper currency whose presence can be detected using a remote detection method.

[0013] United States Patent No. 6,423,412 to Zhang et al. discloses a system using polyvinylidine fluoride (PVDF) polymers that exhibit electrostrictive strain when subjected to electric fields.

[0014] United States Patent No. 6,495,231 to Benoit et al. discloses an epoxy coated multi-layer structure for security documents comprising two layers of High Density Polyethylene (HDPE) polymer encapsulating a layer of oriented polypropylene

(OPP) polymer that provides a high quality sheet material suitable for making banknotes.

[0015] United States Patent No. 6,659,351 to Bailleu et al. discloses a piezoelectric effect-based security feature comprising a polyvinylidine fluoride (PVDF) polymer foil.

[0016] United States Patent No. 7,078,101 to Ramotowski et al., which is assigned to the common assignee of the present application, discloses polyvinylidine fluoride (PVDF) polymers that exhibit electrostrictive strain when subjected to electric fields.

[0017] As described above, there is a need for anti-counterfeiting systems and methods that overcome the deficiencies of the prior art.

SUMMARY OF THE INVENTION

[0018] A primary objective and general purpose of the present invention is to provide a method of testing legal instruments of value, such as paper currency, for authenticity.

[0019] It is also a primary objective of the present invention to produce a legal instrument (such as paper currency) that is readily tested for authenticity.

[0020] It is also an objective of the present invention to provide a legal instrument (such as paper currency) that is readily tested for authenticity using an electrostrictive

polymer that does not require poling and cannot be accidentally depoled.

[0021] It is also an objective of the present invention to provide a legal instrument that is readily tested for its denomination, so as to avoid deliberate or accidental mischaracterization of the value of the paper currency when used in a transaction.

[0022] In accordance with the present invention there is provided a new class of paper currency (and other legal instruments) that are secure against counterfeiting, and against accidental or deliberate mischaracterization of the value of the currency. An embodiment of the invention includes a banknote having one or more structures made of electrostrictive polymer, normally invisible to human observation under ambient conditions, and applied to one or more locations of the currency. The locations can be selected in predetermined positions relative to visible features present on the currency, such as a numerical denomination, an identifier of the nation that issued the currency, an image of a national figure of interest, a seal, a textual denomination of value, and a serial number.

[0023] The electrostrictive polymer can be interrogated by application of an electric field to those areas where the polymer is located. The polymer responds by changing a physical dimension along the direction of the applied electric

field. The change in dimension can be sensed, and provides a signal that is indicative of the authenticity or of the denomination of the banknote.

[0024] The foregoing and other objects, aspects, features, and advantages of the invention will become more apparent from the following description and from the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0025] The objects and features of the invention can be better understood with reference to the drawing described below, and the claims. The drawing is not necessarily to scale, emphasis instead generally being placed upon illustrating the principles of the invention.

FIG. 1 is a diagram that illustrates of some of the features of a notional banknote in accordance with the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0026] This invention involves a non-obvious and novel alteration to the paper used to make United States currency. This alteration is unlikely to be duplicated by currency counterfeiters, but its presence can be detected easily using the proper equipment; thereby, producing a reliable and inexpensive means for the detection of counterfeit currency and/or the verification of the authenticity of suspect

banknotes. These anti-counterfeiting properties are also useful with regard to documents that normally carry a level of confidence such as may be attributed to official papers including passports or other documents purporting to be official, whether or not the documents have an explicit monetary value.

[0027] While the following description will be expressed with relation to paper currency, those of ordinary skill in the art will understand that the systems and methods described herein may find use in relation to other paper documents having value, or that carry an implied level of trust. For simplicity of exposition, and for claim interpretation, the term "legal instrument" as used herein will be understood to denote any of currency (e.g., banknotes), checks, stock or bond certificates, other documents which if genuine or authentic have quantifiable financial value, and official papers, such as passports, identity cards, drivers' licenses, official certificates, and other documents purporting to be authorized by and/or issued by a recognized governmental or business issuer.

[0028] Because of evolving technology, government agencies and issuers of documents having a monetary value, such as currency, checks and bonds, seek to improve their ability to prevent counterfeiting. Agencies of the United States Government need to continuously develop and incorporate into

U.S. paper currency advanced anti-counterfeiting features. These features need to be difficult and/or expensive for a counterfeiter to duplicate, while at the same time still being easy to detect (using the proper equipment) to allow merchants, banks and law enforcement agencies to rapidly and reliably verify whether or not a given bill or banknote is genuine (authentic) or counterfeit. Presently, anti-counterfeiting features incorporated into U.S. currency include (but are not limited to) watermarks, micro-printing, color changing inks, and ultraviolet-fluorescing plastic strips.

[0029] Thus, the present system relies on a knowledgeable person to carefully examine a given banknote by eye (or possibly using a machine adapted to measure or disclose a specific feature of a banknote, such as an ultraviolet lamp) in order to determine that these features are present. If the expected feature is present, then the banknote is considered to be genuine. Because the features generally are visible on banknotes, it is possible for the presently-used anti-counterfeiting features to be duplicated by criminal elements.

[0030] Thus, it would be useful to also include some "hidden" features within U.S. banknotes that can be detected using special equipment to definitively establish the authenticity of suspect bills. U.S. Treasury requirements for banknote processing and durability require that any such

features be rugged and able to withstand various extremes of temperature, moisture, and physical damage (e.g., folding, crumpling, washing, and passing through vending machines, ATMs, and currency counting machines).

ELECTROACTIVE MATERIALS

[0031] Electroactive materials include materials that respond to electric fields by fundamentally different mechanisms. These include electrostrictive materials and piezoelectric materials. Electroactive polymers, including electrostrictive polymers and piezoelectric polymers, change their dimensions (expand/contract) in response to an applied electric field. Many of the best performing electroactive polymers are fluoropolymers. This is a fortuitous development, because such polymers typically are quite durable and highly resistant to chemical degradation. Fibers and thin films made from these polymers can be quite flexible and can be incorporated into the special paper used to make U.S. currency in the form of woven patterns, strips, or small patches of plastic.

ELECTROSTRICTIVE MATERIALS

[0032] Electrostrictive polymers are promising materials for use in currency as an anti-counterfeiting device. These polymers have no remnant polarization, so they cannot be

depoled, and do not need to be poled to be responsive to applied electrical fields in the first place.

[0033] Certain electrostrictive polymers (e.g., VDF-TrFE-CFE; see United States Patent 7,078,101) exhibit large, reversible changes in dimension when subjected to high electric fields. Such polymers can generate a large signal response under the proper conditions. Electroactive polymer fibers, or small, thin pieces of electroactive polymer itself, can be incorporated into the special paper used to make U.S. currency. The electroactive material can be incorporated in such a way that a three dimensional image is generated when the section of the banknote containing the polymer is subjected to a high electric field. This image can be scanned/read by a laser system.

[0034] Alternatively, just the change in dimension that occurs under application of a known field strength can be read by a test apparatus. A banknote or other document would be judged to be genuine if the reading observed was appropriate in response to an electric field applied in the test location. Such a mechanical change in dimension could be sensed in any of several different ways (e.g., using a microelectromechanical, or MEMS, strain gauge, using optical interferometry, or using a capacitance change between two plates of a capacitor separated by the banknote in question).

PIEZOELECTRIC MATERIALS

[0035] Some electroactive polymers are piezoelectric. Piezoelectric materials have a dipole moment in the active state. Piezoelectric materials are less desirable for use in currency because they must be poled in order to be active, and they can be depoled (i.e., rendered inactive) by exposure to high enough heat or to a depoling electric field- such as a electric field of sufficient amplitude. Piezoelectric materials change dimension upon application of an electric field. The materials also change their dipole moment upon application of a physical deformation or application of a physical stress. However, for the purposes of the present disclosure, piezoelectric materials are considered to present disadvantages (e.g., the requirement to pole and the possibility of becoming depoled and inactive) that would militate against their use and would argue for the preferability of using electrostrictive materials.

BANKNOTE DESIGN

[0036] **FIG. 1** is provided to illustrate various features or locations that can be used to identify where an anti-counterfeiting element can be disposed on a banknote. Turning to **FIG. 1**, there is shown diagram that is illustrative of some of the visually or optically recognizable features of a notional banknote. In **FIG. 1** one sees a numerical

denomination **100**, an identifier of the nation that issued the currency **102**, an image **104** of a national figure of interest, a seal **106**, a textual denomination of value **108**, and a serial number **110**. In addition, banknotes normally carry additional visual information, such as a signature of a government official (such as the Secretary of the Treasury) and other distinctive optically recognizable features such as detailed engravings - none of which are illustrated in **FIG. 1**.

[0037] In various embodiments, one can dispose an electrostrictive polymer of known composition in a predetermined location relative to any of the features enumerated herein. One can also use positional information, such as corners of the banknote, four of which are illustrated in **FIG. 1**, as a basis for locating the electrostrictive polymer on the banknote.

[0038] In the following discussion, the electrostrictive polymer that is provided in the one or more locations will be referred to as an "image." Because the electroactive polymers used for this purpose would be fluoropolymers, the pattern or "image" should remain within the banknote throughout a normal circulation lifetime. The banknote can be crumpled, washed, exposed to the elements, and even heated (within certain limits) without destroying the "image."

[0039] The electroactive polymer "image" would not be visible on the banknote under conventional ambient conditions.

In order to provide a system for identifying whether a particular banknote is genuine or counterfeit, a device that is configured to read the one or more regions of electrostrictive polymer needs to be provided (which will be referred to as a "bill verification instrument") whose operation is described further hereinbelow.

[0040] The design and location on the banknote of the electroactive polymer "image" can be changed for different denominations and series of banknotes. Depending on the denomination, one can provide one or more regions containing one or more electrostrictive polymer structures. In some embodiments, different electrostrictive polymers, each of which has a unique response to applied electric fields (as explained in United States Patent No. 7,078,101) can be disposed in different locations on a single banknote - for example to make counterfeiting a banknote of a larger denomination appreciably more difficult than counterfeiting a banknote of a lesser denomination.

BANKNOTE IDENTIFICATION

[0041] In operation, the bill verification instrument would produce a high electric field necessary to reveal the "image." The bill verification instrument would determine whether the correct "image" is present on a banknote subjected to the test. The bill verification instrument could provide a binary

"YES" or "NO" (e.g., genuine or counterfeit) response that would signal the status of a banknote.

[0042] The detection of the "image" would be straightforward with the proper equipment, and a banknote verification instrument could be built that would automate the process and produce a simple yes/no output for bank tellers or merchants to verify whether or not a given banknote is genuine. Once the electric field is turned off, the "image" disappears and the banknote will look normal to the naked eye. In order to maintain security of the system, bill verification instruments used to discriminate genuine and counterfeit banknotes should preferably be available only to entities that are trusted - such as governmental agencies, banks, and other bonded or otherwise trusted individuals or specifically identified facilities.

[0043] The normally invisible "image" can, in some embodiments, be a real pattern that a laser scanner would detect and compare against authentic patterns in its memory banks. In another embodiment, the bill verification instrument could provide a reading of the change in dimension that occurs to a patch of electroactive polymer upon exposure to an electric field of sufficient strength to trigger such a change, and compare those changes against an authentic pattern stored in memory.

[0044] Bill verification instruments used to discriminate genuine and counterfeit banknotes should preferably not be available to the general public, because those who would produce counterfeit banknotes could perform "reverse engineering" to use a bill verification instrument to determine what electroactive polymer is applied in which location on notes of specific types (e.g., notes of specific denominations).

[0045] It is apparent that one who wishes to obtain information about the anti-counterfeiting systems and methods that are being utilized could always attempt a "brute force" analytic approach (for example by examining a sufficient number of banknotes) in a manner similar to cryptanalysis. However, this process requires more sophisticated knowledge and is more difficult and time-consuming than simply operating a known good bill verification instrument on known good banknotes and recording the results of such measurements in order to determine the operational features needed to pass the test.

BANKNOTE DENOMINATION INDICATION

[0046] Persons who have visual impairment can become victims of unscrupulous individuals who may seek to provide incorrect amounts of money during a financial transaction. In some countries, physical features such as raised patches

(similar to Braille printing), or different sizes of paper currency, are used to designate different denominations, which can be helpful to those who are visually impaired.

[0047] The systems and methods of the present application can be used to apply denomination "identifiers" that can be read with an inexpensive, small, portable, (e.g., hand-held) scanner that could be used by blind or visually-impaired people to indicate the denomination of banknotes, which is a different instrument from the bill verification instrument.

[0048] Rather than indicating authenticity, the scanner would express a denomination (using any one or more of a visual display in large type) an aural report, or in a tactile manner, such as in Braille or using the tactile equivalent of a seven segment digital display.

[0049] Such denomination identifiers should be different from the anti-counterfeiting features also described herein. For example, the denomination identifiers should be supplemental to the anti-counterfeiting features, and located in different locations on the banknote, such as in each corner, for ease of testing irrespective of the orientation of the banknote.

[0050] In addition, because the hand-held scanners used to read such denomination identifiers would be widely available; the denomination identifiers would not be appropriate as anti-counterfeiting features. Using this denomination

identification system, there can be provided an infallible "marker" on banknotes for a hand-held scanner to read to allow blind/visually-impaired persons to handle paper currency without the fear of making mistakes or being cheated.

[0051] Another alternative embodiment would be to make patterns on a banknote using other active polymers (e.g., those that change dimensions due to a change in temperature, or those that exhibit a change in polarization upon heating, such as pyroelectric polymers).

[0052] United States Patent No. 6,423,412 is silent as regards any application of polyvinylidine fluoride (PVDF) polymers as security elements in documents. United States Patent No. 6,659,351 is silent regarding electrostrictive properties of polyvinylidine fluoride (PVDF) polymers, and also is silent regarding possible electrostrictive properties of all other polymers, such as those described in other documents (such as United States Patent No. 6,423,412 and United States Patent No. 7,078,101).

[0053] All of the electrostrictive materials described in any of United States Patent No. 6,423,412, United States Patent No. 6,659,351 and United States Patent No. 7,078,101 are candidate materials for use in the systems and methods described herein.

[0054] Any patent, patent application, or patent publication identified in the specification is hereby

incorporated by reference herein in its entirety. Any material, or portion thereof, that is said to be incorporated by reference herein, but which conflicts with existing definitions, statements, or other disclosure material explicitly set forth herein is only incorporated to the extent that no conflict arises between that incorporated material and the present disclosure material. In the event of a conflict, the conflict is to be resolved in favor of the present disclosure as the preferred disclosure.

[0055] It will be understood that many additional changes in the details, materials, steps and arrangement of parts, which have been herein described and illustrated in order to explain the nature of the invention, may be made by those skilled in the art within the principle and scope of the invention as expressed in the appended claims.

Attorney Docket No. 99704

ELECTROACTIVE POLYMERS WITH ANTI-COUNTERFEITING FEATURE

ABSTRACT OF THE DISCLOSURE

The present invention provides a new class of currency and documentation that is secure against counterfeiting, and against accidental or deliberate mischaracterization. The documentation has one or more structures made of electrostrictive polymer, normally invisible to human observation under ambient conditions, applied to one or more locations of the documentation. The locations can be selected in predetermined positions relative to visible features present on the documentation. The electrostrictive polymer can be interrogated by application of an electric field to those areas where the polymer is located. The polymer responds by changing a physical dimension along the direction of the applied electric field. The change in dimension can be sensed, and provides a signal that is indicative of authenticity or denomination. The systems and methods can be applied to other documents.

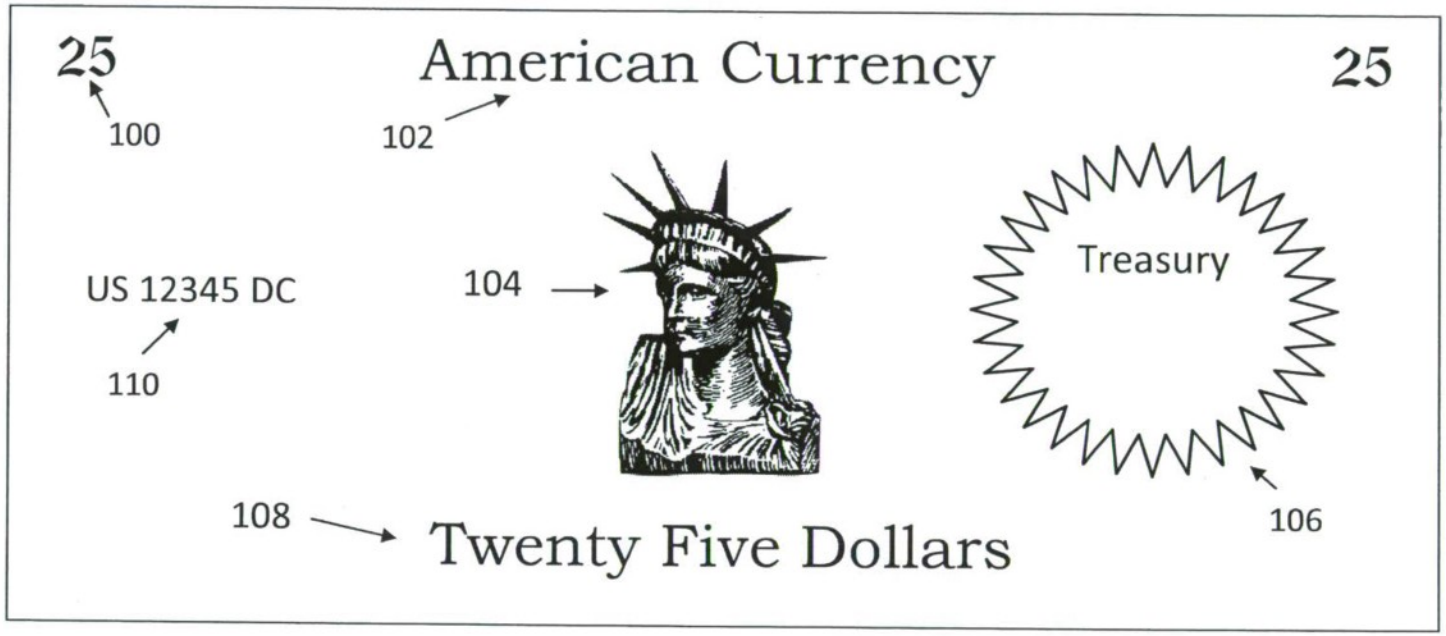
25
American Currency
25
100
102
US 12345 DC
110
104
Treasury
106
108
Twenty Five Dollars

FIG. 1