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(54) **METHOD OF DETERMINING AN AUTHENTICITY OF A VALUE DOCUMENT, METHOD OF MANUFACTURING A VALUE DOCUMENT AND SET OF VALUE DOCUMENTS**

(57) The invention relates to a method of determining an authenticity of a value document (1). In step (S1) of the method a value document (1) having a first luminescent area (11) and a second luminescent area (12) is provided. In step (S2) the first luminescent area (11) is illuminated using a first illumination (21), and in step (S3), upon illuminating the first luminescent area (11) using the first illumination (21), a first luminescence intensity (31) emitted by the first luminescent area is measured. In step (S4), the second luminescent area (12) is illuminated using the first illumination (21), and in step (S5), upon illuminating the second luminescent area (12) using the first illumination (21), a second luminescence intensity (32) emitted by the second luminescent area (12) is measured. In step (S6), an authenticity information is obtained based on the measured first and second luminescence intensities (31, 32).

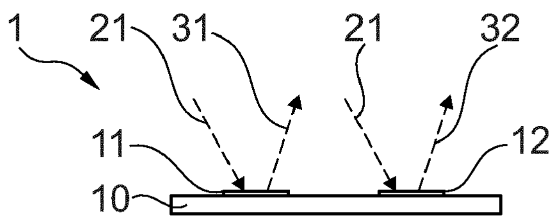


Fig. 3

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## Description

### Technical Field

**[0001]** The disclosure generally relates to security features for value documents. In particular, the invention relates to a method of determining an authenticity or quality of a value document, a method of manufacturing a value document as well as to a set of value documents.

### Technical Background

**[0002]** Value documents are understood as sheet-shaped objects, which represent, for example, a monetary value or an authorization and which should therefore not be manufacturable at will by unauthorized persons. They hence have features, so-called security features, that are not easy to manufacture, in particular to copy, and that allow a user to check authenticity of the value document. An exemplary security element commonly used for such value documents may a printed pattern, which shows a visible luminescence when illuminated with invisible excitation radiation, for example ultraviolet (UV) light. Such a luminescent print can be checked visually, e.g., at a point of sale, by comparing its pattern and/or color to a known reference of a genuine document of value. It is also known to use multi-colored luminescent prints on value documents. These multi-colored luminescent prints often have a high aesthetic value. For visual checks, fluorescent printing inks may be preferred because they allow high luminescence intensity and fine printing details. Furthermore, it is known to check luminescent security elements automatically by measuring the emitted luminescence using an optoelectronic device, for example a photodiode. The measured luminescence can be analyzed regarding its spectral, temporal and/or spatial characteristics and pre-determined parameters may be compared electronically to reference values in order to determine the authenticity of the value document. It is also known to use automated luminescence measurements to sort documents of values into several classes, e.g., denominations. For optoelectronic measurements, phosphorescent printing inks may be preferred because their emission can easily be separated from a fluorescent background which may for example originate from detergents.

### Summary

**[0003]** It may be seen as an object of the invention to provide improved measures for determining the authenticity or quality of value documents.

**[0004]** Two methods and a value document set according to the features of the independent claims are provided. Further embodiments are evident from the dependent claims and from the following description.

**[0005]** According to an aspect, a method of determining an authenticity or quality of a value document is provided. A step of the method comprises providing a value document having a first luminescent area and a second luminescent area. Another step includes illuminating the first luminescent area using a first illumination. Another step comprises upon illuminating the first luminescent area using the first illumination, measuring a first luminescence intensity that is emitted by the first luminescent area. Another step comprises illuminating the second luminescent area using the first illumination. Another step comprises upon illuminating the second luminescent area using the first illumination, measuring a second luminescence intensity that is emitted by the second luminescent area. Another step comprises illuminating the first luminescent area using a second illumination, wherein the first illumination has a first temporal structure and the second illumination has a second temporal structure, wherein the first temporal structure is different from the second temporal structure. Another step comprises upon illuminating the first luminescent area using the second illumination, measuring a third luminescence intensity that is emitted by the first luminescent area. Another step comprises illuminating the second luminescent area using the second illumination. Another step comprises upon illuminating the second luminescent area using the second illumination, measuring a fourth luminescence intensity that is emitted by the second luminescent area. Another step comprises obtaining the authentication or quality information based on a time-averaged luminescence intensity of the measured first luminescence intensity, a time-averaged luminescence intensity of the measured second luminescence intensity, a time-averaged luminescence intensity of the measured third luminescence intensity and a time-averaged luminescence intensity of the measured fourth luminescence intensity. In the method the first illumination is defined by a pulsed illumination that includes multiple consecutive first illumination cycles. Further, the first and second luminescence intensity that is emitted by the first luminescent area and the second luminescent area, respectively, is measured over a first measuring time interval, the first measuring time interval being at least equal to or larger than one of the first illumination cycles.

**[0006]** Still further the time-averaged luminescence intensity of the measured first and second luminescence intensity is determined with respect to the first measuring time interval. Preferably, the first measuring interval corresponds to at least two consecutive first illumination cycles. Herein, the term "quality" is understood to relate a quality of production or manufacture of the value document, in particular the luminescent areas.

**[0007]** Preferably, a signal is output which represents the authentication or quality information. The signal can be used to control further processing of the value document.

**[0008]** The inventive method allows a determination of the authenticity of value documents based on luminescence intensity emissions originating from the luminescent areas upon illuminating these luminescent areas. In particular, if the luminescent areas are illuminated with optical radiation of a specified wavelength, then these luminescent areas may emit distinguishable intensities over a predetermined time span, depending on the materials and material amounts used for the luminescent areas.

**[0009]** The luminescent areas may be defined by respective prints which are located on a surface of the value document or which are embedded within the value document. For example, fluorescent and phosphorescent printing inks with the same or different luminescent color impressions can be combined on the same value document and may then be used for determining the authenticity of the value document. However, instead of determining the authenticity of the value document only based on spectral or temporal criteria for the luminescence, the method allows to use intensity measurements with respect to the luminescence emitted by the luminescent areas in an advantageous manner as will be described in detail herein.

**[0010]** Advantageously, one single sensor may be sufficient to determine authenticity of the value document when using the inventive method. When measuring the first to fourth luminescence intensities preferably the same single sensor may be used for measuring. For example, a security element on the value document which combines fluorescent and phosphorescent prints, or which combines two phosphorescent prints with different phosphorescent decay properties, can be checked using only one single sensor without spectral or temporal resolution. In particular, the authenticity of the value document can be checked using only intensity measurements, in particular time-averaged luminescence intensities, which will be explained in more detail below.

**[0011]** As noted above, the method comprises the provision of a value document which for instance may be a banknote, but also may be a card-like data carrier such as a credit card or smart card, etc. During a manufacturing process, which will also be described in more detail below, the value document may be provided with the first luminescent area and the second luminescent area, for example using various printing techniques. The luminescent areas may be arranged at specified locations on the surface of the value document or may be embedded, at least partly, within the value document. It is possible to arrange the two luminescent areas on the value document such that both luminescent areas appear separated from each other on the value document. However, the luminescent areas may also be arranged next to each other on the value document such that both luminescent areas may appear as a single motif on the value document when being viewed by a user, or when being illuminated with light of a specified wavelength.

**[0012]** The luminescent areas may include different luminescent properties which may be adjusted during the printing process, for example by adjusting an amount of luminescent material or a concentration of luminescent particles, etc. The different luminescent properties of the first and second luminescent areas allow these areas to emit substantially same or different luminescence intensities when being illuminated, based on the specific excitation illumination used.

**[0013]** According to the inventive method, each of the first and the second luminescent area is illuminated using the first illumination, and, upon illuminating the first and the second luminescent area using the first illumination, respective first and second luminescence intensities that are emitted by the first and second luminescent areas are measured. Due to possibly different luminescence properties for the first and the second luminescent area, different, e.g., distinguishable, luminescence intensities emitted from the respective areas may be measured. However, as will be explained hereinafter, the second illumination of the first and second luminescent area may result in substantially identical or indeed identical intensities emitted from the respective luminescent areas. The illuminations used may preferably be chosen to allow excitation of luminescence in the respective luminescent areas.

**[0014]** The first illumination preferably comprises ultraviolet radiation in a wavelength range of 100 nm to 380 nm and may optionally include visible light in the wavelength range of 380 nm to 750 nm. The first illumination may be performed with an ultraviolet (UV) light source. The first illumination may alternatively be performed with an infrared light source that emits infrared radiation in a wavelength range of 750 nm to 2500 nm. The first illumination is a pulsed illumination which includes multiple consecutive first illumination cycles. Each of these cycles may contain an illumination pulse and a pulse pause separating the pulses of consecutive cycles. For example, the first illumination includes multiple illumination pulses over a predetermined time span.

**[0015]** When using the above-mentioned illumination modalities for the first illumination, different emission intensities may be measured for the first luminescence intensity and for the second luminescence intensity. The measured first luminescence intensity and the measured second luminescence intensity may then be used to determine the authenticity or quality of the value document. For example, the time-averaged measured first luminescence intensity and the time-averaged measured second luminescence intensity may be compared to each other. If a ratio of the time-averaged measured intensities shows a predetermined value different from 1 or lies within a predetermined value range not including 1, then the authenticity of the value document may be affirmed and/or an affirmative authentication information may be provided. If, on the other hand, the ratio of the time-averaged measured intensities does not show a predetermined amount or does not lie within a predetermined value range, the authenticity of the value document may be declined and/or a negative authentication information may be provided. In this manner, authenticities of each one of a sequence of value documents can be checked by applying the inventive method for every single value document. In the case of determining the quality of the value document a deviation between the third and fourth luminescent intensities, e. g. ratio or difference, may be obtained. The corresponding result may be output for further use, e. g. for manufacturing a set of value documents of the same type.

**[0016]** The method further comprises illuminating the first luminescent area using the second illumination, wherein the first illumination has a first temporal structure and the second illumination has a second temporal structure, wherein the first temporal structure is different from the second temporal structure. The method further comprises, upon illuminating the first luminescent area using the second illumination, measuring a third luminescence intensity that is emitted by the first luminescent area, and obtaining the authentication information further based on the measured third luminescence intensity. The method further comprises illuminating the second luminescent area using the second illumination, and, upon illuminating the second luminescent area using the second illumination, measuring a fourth luminescence intensity that is emitted by the second luminescent area, and obtaining the authentication information further based on the measured fourth luminescence intensity.

**[0017]** The second illumination may be performed before or after the first illumination. It is noted that the second illumination is different from the first illumination. In particular, the illumination modalities between first and second illumination may differ. In contrast to the first illumination, the second illumination may be continuous at a fixed illumination intensity, for example by using a continuous wave (cw) during a second illumination time span. This has the advantage that, for the second illumination, a simple continuous lamp can be used, for example a UV hand lamp at a point of sale. The second illumination preferably comprises ultraviolet radiation in a wavelength range of 100 nm to 380 nm and may optionally include visible light in the wavelength range of 380 nm to 750 nm. In an example, the second illumination may be performed with an ultraviolet (UV) light source. The second illumination may alternatively be performed with an infrared light source that emits infrared radiation in a wavelength range of 780 nm to 2500 nm.

**[0018]** It may be preferred to use a pulsed illumination over a predetermined time span for the first illumination and a continuous, preferably constant, illumination for the second illumination. In other words, it is possible that the first illumination is represented by a pulsed illumination over a predetermined time span, wherein the first illumination is defined by multiple illumination pulses separated by respective non-illumination gaps or pulse pauses, and that the second illumination is represented by a constant illumination over the same predetermined time span, wherein the second illumination is defined by a constant illumination intensity without substantial intensity variations during said time span.

**[0019]** As described above, the method further comprises illuminating the second luminescent area using the second illumination, and, upon illuminating the second luminescent area using the second illumination, measuring a fourth luminescence intensity that is emitted by the second luminescent area, and obtaining the authentication information further based on the measured fourth luminescence intensity.

**[0020]** Thus, the first luminescent area as well as the second luminescent area are illuminated with the second illumination. Therefore, according to the inventive method, each of the first and the second luminescent area is also illuminated using the second illumination and, upon illuminating the first and the second luminescent area using the second illumination, respective third and fourth luminescence intensities that are emitted by the first and second luminescent areas are measured.

**[0021]** The method further comprises obtaining the authentication or quality information based on a time-averaged luminescence intensity of the measured first luminescence intensity and a time-averaged luminescence intensity of the measured second luminescence intensity, a time-averaged luminescence intensity of the measured third luminescence intensity and a time-averaged luminescence intensity of the measured fourth luminescence intensity.

**[0022]** It is possible to obtain the authentication or quality information based on determining a ratio between the time-averaged luminescence intensity of the measured first luminescence intensity and the time-averaged luminescence intensity of the measured second luminescence intensity. In addition, it is possible to obtain the authentication information based on determining another ratio between the time-averaged luminescence intensity of the measured third luminescence intensity and the time-averaged luminescence intensity of the measured fourth luminescence intensity. Instead of determining ratios, differences can also be used.

**[0023]** The time-averaged luminescence intensity may be determined by measuring an intensity of the luminescence over a predetermined time interval and then determining the average luminescence intensity occurring within this time interval. The time-averaged luminescence intensity may be determined by measuring an intensity of the luminescence using a capture device with a low temporal resolution. In this case, the measuring time interval may correspond to the temporal resolution of the capture device. This may apply for determining the time-averaged luminescence intensity of each one of the first, second, third and fourth luminescence intensity.

**[0024]** According to an embodiment, the method further comprises illuminating the first luminescent area using the first illumination over a first illumination time interval and measuring the first luminescence intensity that is emitted by the first luminescent area over a first measuring time interval, the first measuring time interval being at least equal to or larger than the first illumination time interval, wherein the time-averaged luminescence intensity of the measured first luminescence intensity is determined with respect to the first measuring time interval.

It is possible that the time-averaged luminescence intensity of each of the second, third and fourth luminescence intensity is determined according to the same principles as the time-averaged luminescence intensity of the measured first luminescence intensity.

**[0025]** For example, if a pulsed illumination is used for the first illumination, the measurement of the time-averaged luminescence intensity of the first and second luminescence intensities may be performed over the first measuring time interval which is preferably larger than the first illumination time interval that contains several illumination pulses. In particular, the first and second luminescent areas may have different decay time properties for their emitted intensities upon illumination such that, after an illumination pulse has ended, the first luminescence intensity may decrease faster than the second luminescence intensity. Alternatively or in addition, the first and second luminescent areas may have different rise time properties for their emitted intensities upon illumination, such that during an illumination pulse, the first luminescence intensity may increase faster than the second luminescence intensity. As a result, the time-averaged luminescence intensity of the measured first luminescence intensity may be smaller than the time-averaged luminescence intensity of the measured second luminescence intensity.

**[0026]** The corresponding intensities are averaged over at least one whole cycle of the first illumination. Preferably, the intensities are averaged over several, preferably between 10 and 100, periods of the first illumination. This reduces artifacts due to a possible lack of synchronization between the intensity measurement and the illumination.

**[0027]** In case a pulsed illumination is also used for the second illumination, preferably, the corresponding intensities are averaged over at least one whole cycle of both the first and the second illumination. More preferably, the intensities are averaged over several, preferably between 10 and 100, periods of both illuminations. This reduces artifacts due to a possible lack of synchronization between the intensity measurement and the illumination.

**[0028]** Preferably, the second measuring time interval equals the first measuring time interval and / or the fourth measuring time interval equals the third measuring time interval. More preferably, all four measuring time intervals are equal.

**[0029]** As explained above, the first illumination has a first temporal structure and the second illumination has a second temporal structure, wherein the first temporal structure is different from the second temporal structure.

**[0030]** In the present context, the expression "different temporal structure" may be understood in that the first and the second illumination may be modulated in a different way. In one example, the first illumination can be pulsed or intensity modulated, and the second illumination can be continuous at a fixed intensity, i.e., a continuous wave (cw). This has the advantage that for the second illumination, a simple continuous lamp can be used, e.g. a UV hand lamp at a point of sale.

**[0031]** Furthermore, it is possible that both the first and the second illumination are pulsed illuminations. In this case, the first and the second illumination may differ in their repetition rate, pulse width and/or duty cycle. Therefore, in case of pulsed illuminations, the temporal structure for the respective illuminations may be distinguishable with respect to an illumination pulse frequency. As already indicated above, the intensity may be averaged over time scales larger than the expected decay constants and/or over at least one whole repetition cycle of the illumination.

**[0032]** According to an embodiment, the first illumination is defined by a pulsed illumination that includes multiple illumination cycles and/or the second illumination is defined by a constant illumination.

**[0033]** In particular, during the first illumination, the first and second luminescent areas are illuminated with a pulsed illumination that contains several cycles or in particular several illumination pulses over the first illumination time interval. The pulsed illumination may be defined by an alternating change between different illumination intensities over the first illumination time interval, in particular, the illumination is periodically switched on an off. In contrast, during the second illumination, the first and second luminescent areas may be illuminated with a constant illumination, i.e., with a constant illumination intensity, over a second illumination time interval.

**[0034]** In a preferred example, the luminescence properties for the first and the second luminescent area are adjusted such that, upon illuminating them with the second illumination, the time-averaged luminescence intensities emitted from the respective luminescent areas are substantially identical or indeed identical, i.e., the ratio of the time-averaged luminescence intensities emitted from the respective luminescent areas differs from 1 by not more than a specified threshold value.

**[0035]** Consequently, upon illumination of both luminescent areas with the first illumination, the method may determine emitted first and second luminescence intensities which are different to each other, e.g., a ratio between first and second time-averaged luminescence intensities is substantially different from 1 by more than a predetermined threshold value. Accordingly, upon illumination of both luminescent areas with the first illumination, the method may determine time-averaged emitted first and second luminescence intensities which are different from each other, e.g., a ratio between time-averaged first and second luminescence intensities has a predetermined value different from 1, or lies within a predetermined value range not including 1. If these determinations are made, an affirmative authentication information may be provided based thereon.

**[0036]** According to an embodiment, the first luminescent area is defined by a fluorescent print on the value document and the second luminescent area is defined by a phosphorescent print on the value document. For the purpose of this invention, fluorescence may include any luminescence with a decay time smaller than 1 $\mu$s, while phosphorescence may include any luminescence with a decay time greater than 1 $\mu$s.

**[0037]** A fluorescent print may have the property that the fluorescence intensity, upon illumination, immediately follows the illumination pulse form. In particular, there might be no substantial decay times after the illumination during which the fluorescent print still luminesces. In contrast, the phosphorescence print may have the property that the phosphorescence intensity shows a marked rise and decay behavior with the intensity not returning to zero in-between illumination pulses.

**[0038]** Thus, the fluorescent and phosphorescent prints may differ in the decay constant of their luminescence, for example the prints may provide at least 50 % difference in their decay times, i.e., $(MAX(\tau_1, \tau_2) - MIN(\tau_1, \tau_2)) / MIN(\tau_1, \tau_2) > 0.5$, wherein $\tau_1$ is the luminescence decay constant for the fluorescent print and $\tau_2$ is the luminescence decay constant for the phosphorescent print.

**[0039]** According to an embodiment, the first luminescent area is defined by a first phosphorescent print on the value document and the second luminescent area is defined by a second phosphorescent print on the value document, wherein first phosphorescent print and the second phosphorescent print comprise different luminescence decay properties, for example with at least 50% different decay times.

**[0040]** Thus, both phosphorescent prints may differ in the decay constant of their luminescence, for example the phosphorescent prints may provide at least 50% difference in their decay times, i.e., $(MAX(\tau_1, \tau_2) - MIN(\tau_1, \tau_2)) / MIN(\tau_1, \tau_2) > 0.5$, wherein $\tau_1$ is the luminescence decay constant for the first phosphorescent print and $\tau_2$ is the luminescence decay constant for the second phosphorescent print.

**[0041]** According to an embodiment, the first illumination and the second illumination comprise substantially identical spectral compositions and/or the first illumination and the second illumination comprise substantially identical spatial illumination distributions. For example, the same light source may be used for the first and second illuminations.

**[0042]** It is possible to differentiate between a fluorescence emission and a phosphorescence emission or between two phosphorescence emissions using only the time-averaged luminescence intensity. To this end, at least two different illumination conditions, i.e., the abovementioned first and the second illumination, may be used. In particular, the first and the second illumination can have the same spectral and spatial distribution and might only differ in their temporal structure as indicated above. This has the advantage that only one single illumination source is necessary for both illuminations.

**[0043]** According to an embodiment, the first luminescent area and the second luminescent area are configured to be visible with substantially identical colors, upon being illuminated with the first illumination, and/or the first luminescent area and the second luminescent area are configured to be visible with substantially identical colors, upon being illuminated with the second illumination.

**[0044]** In other words, the first and the second luminescent area have the same color impression upon illumination with the first illumination and/or the second illumination. This has the advantage that the first and second luminescent area together appear as a homogeneous motif on the value document during illumination.

**[0045]** In an example, the first and the second luminescent area have the same color impression, at least upon the first illumination, which makes it easier to discern, i.e., measure, the intensity difference or ratio as described above.

**[0046]** According to an aspect, a method of manufacturing a set of value documents with an authentication feature is provided. The method comprises providing a set of value documents. For each of the value documents of the set the following steps are performed: Providing a first luminescent material with first luminescent material characteristics and providing a second luminescent material with second luminescent material characteristics. Applying the first luminescent material onto the value document in order to provide a first luminescent area on the value document and applying the second luminescent material onto the value document in order to provide a second luminescent area on the value document. The first luminescent area is configured to emit a first luminescence intensity, upon illumination with a first illumination, and to emit a third luminescence intensity, upon illumination with a second illumination that is different to the first illumination. Further, the second luminescent area is configured to emit a second luminescence intensity upon illumination with said first illumination and a fourth luminescence intensity upon illumination with said second illumination.

**[0047]** The method further comprising for at least one value document of said set determining a quality of said value document using a method of determining a quality of the value document according to the invention wherein the quality information includes a ratio between the third luminescence intensity and the fourth luminescence intensity.

**[0048]** In the method of manufacturing said applying the second luminescent material onto one of the the value document of the set includes adjusting an amount of the second luminescent material applied onto the value document using the quality information obtained for said preceding value document which the determining was effected for, thereby enabling the second luminescent area to emit a fourth luminescence intensity, upon illumination with the second illumination. The amount of the second luminescent material is adjusted such that a ratio between the time-averaged emitted third luminescence intensity and the time-averaged emitted fourth luminescence intensity may be substantially equal to 1, preferably between 0.8 and 1.2, more preferably between 0.9

and 1.1.

**[0049]** According to an embodiment, applying the first luminescent material onto the value document and/or applying the second luminescent material onto the value document includes using at least one of an offset printing, a flexography printing, an intaglio printing, a screen printing, a letterpress printing or a numbering printing. One or more of these printing techniques can be used to print the first and/or second luminescent material onto the surface of the value document.

**[0050]** According to an aspect, a set of value documents, in particular manufactured using a method of manufacturing according to the invention, is provided. The set of value documents comprises a first value document having a first luminescent area and a second luminescent area as well as a second value document having a first luminescent area and a second luminescent area. For each of the first value document and the second value document: the first luminescent area is configured to emit a first luminescence intensity, upon illumination with a first illumination; the second luminescent area is configured to emit a second luminescence intensity, upon illumination with the first illumination; the first luminescent area is further configured to emit a third luminescence intensity, upon illumination with a second illumination that is different to the first illumination; and the second luminescent area is configured to emit a fourth luminescence intensity, upon illumination with the second illumination. For each of the first value document and the second value document: a first ratio between the time-averaged emitted third luminescence intensity and the time-averaged emitted fourth luminescence intensity may be substantially equal to 1, preferably between 0.8 and 1.2, more preferably between 0.9 and 1.1, and a second ratio between the time-averaged emitted first luminescence intensity and the time-averaged emitted second luminescence intensity may substantially equal a specified value which is different from 1, preferably less than 0.8 or greater than 1.2. A ratio between the second ratio for the first value document and the second ratio for the second value document may be substantially equal to 1, preferably between 0.9 and 1.1.

**[0051]** In particular, the first ratio between the emitted third luminescence intensity and the emitted fourth luminescence intensity is substantially equal to 1 since the third luminescence intensity and the emitted fourth luminescence intensity may be substantially identical or indeed identical. For example, the following relation between the third luminescence intensity $I_3$ and the fourth luminescence intensity $I_4$ may apply: $|I_4/I_3 - 1| < 0.2$, more preferably $|I_4/I_3 - 1| < 0.1$. Therefore, the third and fourth luminescent areas may appear with approximately the same brightness, upon illumination with the second illumination.

**[0052]** Furthermore, the second ratio substantially differs from 1. This may be due to the fact that the emitted first luminescence intensity and the emitted second luminescence intensity differ by more than a specified threshold value. Due to this greater difference between the emitted first luminescence intensity and the emitted second luminescence intensity, the first and second luminescent areas may appear with different brightness, upon illumination with the first illumination.

**[0053]** Accordingly, the first and second luminescent areas may appear with different brightness upon the first illumination, but with the same brightness upon the second illumination. This may apply for every value document of the set of value documents. In particular, the ratio between the second ratio for the first value document and the second ratio for the second value document is substantially equal to 1. In other words, the deviation in brightness for the first and second luminescent area upon the first illumination is substantially identical or indeed identical for each value document of the set of value documents. In other words, the second ratio substantially equals a predetermined value for each value document of the set of value documents.

**[0054]** According to an embodiment, for both the first value document and the second value document, the first luminescent area is defined by a fluorescent print on the value document and the second luminescent area is defined by a phosphorescent print on the value document.

**[0055]** According to an embodiment, for both first value document and second value document, the first luminescent area is defined by a first phosphorescent print on the value document and the second luminescent area is defined by a second phosphorescent print on the value document, wherein the first phosphorescent print comprises a first luminescence decay time and the second phosphorescent print comprises a second luminescence decay time, wherein the second luminescence decay time is at least 50% longer than the first luminescence decay time.

**[0056]** According to an embodiment, upon illumination with the second illumination,

the first luminescent area and the second luminescent area are visible with substantially identical colors and substantially the same brightness.

**Brief description of the drawings**

**[0057]** The present invention will hereinafter be described in conjunction with the following drawing figures, wherein like numerals denote like elements.

Fig. 1 shows a value document having a first luminescent area and a second luminescent area.

Fig. 2 shows a value document having a first luminescent area and a second luminescent area that together provide a single motif.

Fig. 3 shows a value document having a first luminescent area and a second luminescent area upon illumination with a first illumination.

Fig. 4 shows a value document having a first luminescent area and a second luminescent area upon illumination with a second illumination.

Fig. 5 shows a flow diagram for a method of determining an authenticity of a value document.

Fig. 6 shows diagrams representing intensity distributions for the illumination and the luminescence of two different luminescent materials over time.

Fig. 7 shows further diagrams representing intensity distributions for the illumination and the luminescence of two different luminescent materials over time.

Fig. 8 shows two value documents, each of which is illuminated with a first and a second illumination.

Fig. 9 shows a flow diagram for a method of manufacturing a value document with an authentication feature.

**Detailed description of exemplary embodiments**

**[0058]** The representations and illustrations in the drawings may be schematic and not to scale. A better understanding of the methods and the value document set described above may be obtained through a review of the shown illustrations together with a review of the detailed description that follows.

**[0059]** Fig. 1 shows a value document 1 having a first luminescent area 11 and a second luminescent area 12. The value document 1 may be a banknote, wherein the first luminescent area 11 and the second luminescent area 12 may be printed on a surface 10 of the value document 1. However, it is noted that alternative forms of value documents 1 may be used. In the example of Fig. 1, each of the first luminescent area 11 and the second luminescent area 12 cover only a part of the surface 10 of the value document 1, wherein both luminescent areas 11, 12 are separated from each other by a certain distance. The first and second luminescent areas 11, 12 may together provide a security feature or security element for the value document 1 which allows to determine an authenticity of the value document 1, for example using a method as described with reference to Fig. 5 below.

**[0060]** Fig. 2 shows an alternative example of a value document 1 having a first luminescent area 11 and a second luminescent area 12 that together provide a single motif. The shape of the motif can be modified individually. It is possible that the single motif visibly appears to a user viewing the value document 1. The first and second luminescent areas 11, 12 may thus have the same color impression upon illumination with white light, in particular both luminescent areas 11, 12 appear colorless. It is possible that the two luminescent areas 11, 12 may be made visible to the user under certain illumination conditions. It may be preferred that both the first and the second luminescent area 11, 12 are invisible under daylight. This increases counterfeit resilience since the security element is invisible under daylight.

**[0061]** Fig. 3 shows a value document, for example the value document 1 of Figs. 1 or 2, having the first luminescent area 11 and the second luminescent area 12, wherein both the first and the second luminescent area 11, 12 are illuminated with a first illumination 21. It is noted that the first luminescent area 11 may be defined by a fluorescent print and the second luminescent area 12 may be defined by a phosphorescent print. However, it is possible that first luminescent area 11 may be defined by a first phosphorescent print and the second luminescent area 12 may be defined by a second phosphorescent print, wherein the phosphorescent prints comprise different decay time properties.

**[0062]** The first illumination 21 may be a pulsed illumination provided by a light source (not shown). Upon illuminating the first luminescent area 11 using the first illumination 21, the luminescent property of the material of the first luminescent area 11 generates a luminescence from the first luminescent area 11 such that a quantifiable first luminescent intensity 31 is emitted from the first luminescent area 11. This first luminescent intensity 31 can be measured, for example by a capture device (not shown) that is configured to capture and measure the first intensity 31 emitted from the first luminescent area 11. In addition, as further shown in Fig. 3, the second luminescent area 12 may also be illuminated by the first illumination 21, to illuminating the first luminescent area 11 with the first illumination 21. Upon illuminating the second luminescent area 12 using the first illumination 21, the luminescent property of the material of the second luminescent area 12 generates a luminescence from the second luminescent area 12 such that a quantifiable second luminescent intensity 32 is emitted from the second luminescent area 12. This second luminescent intensity 32 can also be measured, for example by the above-mentioned capture device that is configured to capture and measure the second intensity 32 emitted from the second luminescent area 12. Based on the measured first luminescence intensity 31 and the measured second luminescence intensity 32, preferably based on a time-averaged first luminescence intensity 31 and a time-averaged second luminescence intensity 32, an authenticity of the value document 1 can be determined.

**[0063]** Fig. 4 shows the value document 1 of Fig. 3, wherein the first luminescent area 11 and the second luminescent area 12 are illuminated with a second illumination 22 provided by a light source (not shown). The second illumination 22 may be different to the first illumination 21, for example in terms of a temporal structure of the illumination. The first illumination 21 and the second illumination 22 may be carried out subsequently and over corresponding illumination time intervals. In particular, the first illumination 11 may be carried out during a first illumination time interval and the second illumination 12 may be carried out during a second illumination time interval, wherein both intervals may be separated by a non-illumination time interval. The first illumination 21 may be carried out before or after the second illumination 22. That is, the order of the illuminations may be varied as required.

**[0064]** The second illumination 22 may be defined by a constant illumination over the entire second illumination time interval. Upon illuminating the first luminescent area 11 using the second illumination 22, the luminescent property of the material of the first luminescent area 11 generates a luminescence from the first luminescent area 11 such that a quantifiable third luminescent intensity 33 is emitted from the first luminescent area 11. This third luminescent intensity 33 can be measured, for example by the above-mentioned capture device that is configured to capture and measure the third intensity 33 emitted from the first luminescent area 11. In addition, as further shown in Fig. 4, the second luminescent area 12 may also be illuminated by the second illumination 22, to illuminating the first luminescent area 11 with the second illumination 22. Upon illuminating the second luminescent area 12 using the second illumination 22, the luminescent property of the material of the second luminescent area 12 generates a luminescence from the second luminescent area 12 such that a quantifiable fourth luminescent intensity 34 is emitted from the second luminescent area 12. This fourth luminescent intensity 34 can also be measured, for example by the above-mentioned capture device that is configured to capture and measure the fourth intensity 34 emitted from the second luminescent area 12. Based on the measured third luminescence intensity 33 and the measured fourth luminescence intensity 34, in particular based on a time-averaged third luminescence intensity 33 and a time-averaged fourth luminescence intensity 34, an authenticity of the value document 1 can be determined.

**[0065]** In another example, the authenticity of the value document 1 is determined based on the time-averaged first, second, third and fourth luminescence intensities 31, 32, 33, 34.

**[0066]** Fig. 5 shows a flow diagram for a method of determining an authenticity of a value document, for example the value document 1 as described with reference to Figs. 1 to 4. In the following, the authentication method will be described with particular reference to the value document of Figs. 3 and 4.

**[0067]** In a step S1, the method comprises providing a value document 1 having a first luminescent area 11 and a second luminescent area 12. In a step S2, the method comprises illuminating the first luminescent area 11 using a first illumination 21. In a step S3, the method comprises measuring a first luminescence intensity 31 that is emitted by the first luminescent area, upon illuminating the first luminescent area 11 using the first illumination 21. In a step S4, the method comprises illuminating the second luminescent area 12 using the first illumination 21. In a step S5, the method comprises measuring a second luminescence intensity 32 that is emitted by the second luminescent area 12, upon illuminating the second luminescent area 12 using the first illumination 21. In a step S6, the method comprises obtaining an authentication information based on the measured first luminescence intensity 31 and the measured second luminescence intensity 32, in particular on the time-averaged measured first luminescence intensity 31 and the time-averaged measured second luminescence intensity 32.

**[0068]** In a further step S7, the method may comprise illuminating the first luminescent area 11 using a second illumination 22, wherein the second illumination 22 is different from the first illumination 21 as described above with reference to Figs. 3 and 4. In a further step S8, the method may comprise measuring a third luminescence intensity 33 that is emitted by the first luminescent area 11, upon illuminating the first luminescent area 11 using the second illumination 22. In a further step S61, the method may comprise obtaining the authentication information further based on the measured third luminescence intensity 33, in particular on time-averaged measured third luminescence intensity33.

**[0069]** In a further step S9, the method may comprise illuminating the second luminescent area 12 using the second illumination 22 which, as described above, is different from the first illumination 21. In a further step S10, the method may comprise measuring a fourth luminescence intensity 34 that is emitted by the second luminescent area 12, upon illuminating the second luminescent area 12 using the second illumination 22. In a further step S62, the method may comprise obtaining the authentication information further based on the measured fourth luminescence intensity 34, in particular on the time-averaged measured fourth luminescence intensity 34.

**[0070]** It is possible to make a first judgement of authenticity based on the luminescent image, e.g., a pattern and/or a color impression of the luminescent areas 11, 12, upon the first illumination 21, and only in case of positive judgement proceed to the second illumination 22, or vice versa.

**[0071]** Fig. 6 shows diagrams representing intensity distributions $I_{21}$, $I_{22}$ for the illumination and the luminescence of two different luminescent materials over time t.

**[0072]** The lower illustration in Fig. 6 shows a pulsed illumination with illumination cycles having a pulse with a pulse duration and corresponding pulse gaps. This pulsed illumination may represent the first illumination 21 as described with reference to Figs. 1 to 5 above. The pulse durations of the pulsed illumination 21 are depicted in the form of rectangles, wherein the pulse gaps have an illumination intensity equal to zero, i.e., between the rectangles. It is assumed that the first luminescent area 11 (cf. Figs. 1 to 4) is a fluorescent print and the second luminescent area 12 (cf. Figs. 1 to 4) is a phosphorescent print. In this case, the fluorescence intensity $I_f$ (cf. first luminescence intensity 31 in Fig. 3) almost immediately follows the illumination pulse distribution. However, the phosphorescence intensity $I_p$ (cf. second luminescence intensity 32 in Fig. 3) shows a marked rise and decay behavior, with the phosphorescence intensity $I_p$ not returning to zero in-between the illumination pulses. Therefore, the time-averaged phosphorescence intensity $\overline{I}_p$ that is indicated by a circle on the righthand side in Fig. 6 is greater than the time-averaged fluorescence intensity $\overline{I}_f$ that is indicated by a square on the righthand side in Fig. 6. As a result, the fluorescent area 11 and the phosphorescent area 12 visually appear with a different brightness under the pulsed (first) illumination 21. Preferably, the intensities are measured and average over several periods of illuminations to obtain the time-averaged intensities. This may reduce the occurrence of artifacts due to a possible lack of synchronization between the intensity measurement and the illumination.

**[0073]** The upper illustration in Fig. 6 shows a constant illumination represented by a constant illumination intensity. This constant (cw) illumination may represent the second illumination 22 as described with reference to Figs. 1 to 5 above. Again, it is assumed that first luminescent area 11 (cf. Figs. 1 to 4) is a fluorescent print and the second luminescent area 12 (cf. Figs. 1 to 4) is a phosphorescent print. In this case, the fluorescent and phosphorescent prints take on their respective saturation intensities when illuminated with the constant illumination 22. Preferably, the fluorescence intensity $I_f$ (cf. third luminescence intensity 33 in Fig. 4) and the phosphorescence intensity $I_p$ (cf. fourth luminescence intensity 34 in Fig. 4), upon the constant (second) illumination 22, are substantially equal, in particular differ by less than 20 %, preferably by less than 10 %. In particular, the time-averaged phosphorescence intensity $\overline{I}_p$ that is indicated by a circle on the righthand side in Fig. 6 is substantially equal to the time-averaged fluorescence intensity $\overline{I}_f$ that is indicated by a square on the righthand side in Fig. 6. As a result, the fluorescent area 11 and the phosphorescent area 12 visually appear with equal brightness under the constant (second) illumination 22. In an especially preferred example, the fluorescent area 11 and the phosphorescent area 12, upon the constant (second) illumination 22, visually appear with substantially equal brightness and substantially equal color impression, e.g., with a color distance of $\Delta E < 3$. Preferably, the first and the second luminescent area 11, 12 together appear as a single motif which increases counterfeit resilience, since upon visual inspection by a user - either under white light or under the second illumination -, it is not apparent that the security element comprises two different luminescent substances.

**[0074]** It is advantageous to choose a constant illumination as the second illumination 22 where the two different luminescent areas 11, 12 emit substantially the same luminescence intensities $I_f$ and $I_p$, since this ensures that all printed luminescent areas 11, 12 can be viewed by a user at full intensity, hence resulting in pleasant aesthetics. Furthermore, this constant illumination condition allows an easy quantitative comparison of the luminescent intensity of the two different luminescent areas 11, 12, when for example an unfiltered Si-photodiode is used. Independently of the specific detection bandwidth chosen for the photodiode detection circuitry, two well defined intensity measures are established and can be measured once the measurement time is sufficiently long to achieve steady state conditions of the detection circuitry. This may also work in case two different visual colors are used for the two different luminescent areas 11, 12. It is beneficial to use a simple luminescence detector as quality control device during printing of the two different areas in order to ensure that the specified intensity conditions are being met for every value document produced.

**[0075]** Fig. 7 shows further diagrams representing intensity distributions $I_{21}$, $I_{22}$ for the illumination and the luminescence of two different luminescent materials over time t.

**[0076]** The lower illustration in Fig. 7 shows a first pulsed illumination with illumination cycles having a pulse with a pulse duration and corresponding pulse gaps. This first pulsed illumination may represent the first illumination 21 as described with reference to Figs. 1 to 5 above. The pulse durations of the first pulsed illumination 21 are present in the form of rectangles, wherein the pulse gaps have an illumination intensity equal to zero, i.e., between the rectangles.

**[0077]** The upper illustration in Fig. 7 shows a second pulsed illumination with a pulse duration and corresponding pulse gaps. This second pulsed illumination may represent the second illumination 22 as described with reference to Figs. 1 to 5 above. The pulse durations of the second pulsed illumination 22 are also present in the form of rectangles, wherein the pulse gaps have an illumination intensity equal to zero, i.e., between the rectangles.

**[0078]** As can be recognized from a comparison of the upper and lower diagram in Fig. 7, both the first and second illuminations 21, 22 are pulsed or modulated, but with a different pulse duration and/or frequency and/or duty cycle. In particular, Fig. 7 shows the case of a first illumination 21 and a second illumination 22 with the same pulse duration but with different pulse gaps. For the first illumination 21 with short pulse gaps (lower diagram), the phosphorescence intensity $I_p$ does not return to zero. Here time-averaged intensities are obtain as described above. In this case, the time-averaged phosphorescence intensity $\overline{I}_p$ is higher than the time-averaged fluorescence intensity $\overline{I}_f$ (cf. circle for the time-averaged phosphorescence intensity $\overline{I}_p$ and square for the time-averaged fluorescence intensity $\overline{I}_f$ on the righthand side in Fig. 7). For the second illumination 22 with long pulse gaps (upper diagram), both the fluorescence intensity If and the phosphorescence $I_p$ intensity return to zero in-between the illumination pulses. In this case, the time-averaged phosphorescence intensity $\overline{I}_p$ is substantially equal or indeed equal to the time-averaged fluorescence intensity $\overline{I}_f$ (cf. circle for the time-averaged phosphorescence intensity $\overline{I}_p$ and square for the time-averaged fluorescence intensity $\overline{I}_f$ on the righthand side in Fig. 7). In a preferred embodiment, the time-averaged intensities upon the second illumination 22 are substantially equal or differ by not more than 10%.

**[0079]** Preferably, the fluorescence and phosphorescence intensities $I_f$, $I_p$ are measured and averaged over at least one whole cycle of both the first and second illumination 21, 22. More preferably, the intensities are averaged over several periods of both illuminations which may reduce artifacts occurring due to a possible lack of synchronization between the intensity measurement and the illumination.

**[0080]** Preferably, both the first and the second luminescent areas 11, 12 are invisible under daylight. This increases counterfeit resilience since the security element is invisible under daylight. In an alternative embodiment, the first and second luminescent areas 11, 12 have the same color impression under daylight, e.g., a color distance of $\Delta E < 3$. In this case, it is preferred that the first and second luminescent areas 11, 12 together appear as a single motif. This increases counterfeit resilience since under daylight it is not readily apparent that the security element comprises two different printing inks.

**[0081]** A sensor may be used as capture device for the authentication method, e.g., to receive the above-mentioned luminescence intensities. The sensor may be a single-track luminescence detector with one UV LED (ultraviolet light emitting diode) and one Si-photodiode (silicon photodiode) with a UV-block filter, where the different illumination conditions are defined using different pulse trains (including cw illumination) for an LED driver. The frequency bandwidth of the detection circuitry can preferably be designed to be less than the maximum frequency of the conditions for the first and second illumination 21, 22. This ensures that a time-averaged intensity can be easily measured and a good signal-to-noise ratio can be achieved due to the rather small frequency bandwidth.

**[0082]** In some embodiments, multiple parallel tracks, e.g., 5, 10, 50, 100, etc., can be used in order to achieve spatial resolution, not only along the path of a transported value document, but also perpendicular to the transport direction. Furthermore, a sensor with spectral resolution can be employed. This improves the selectivity of the authentication method, since different colors of the UV-VIS luminescence can be quantitatively distinguished. Preferably, either two or three spectrally filtered detection channels per measurement track with broadly overlapping spectral sensitivity can be used. This broad overlap may be important to avoid excessive variations of the measured signals caused by slight manufacturing variations of the filter spectra and allows a reasonable separation of different colors, since continuously varying color values can be created from the intensity ratio of the two or three detection channels. The example with three channels provides a more accurate color recognition. In the example with multiple spectral channels, the overall measurement strategy may remain the same, where the spectral information (channel intensity ratio) during at least one illumination is evaluated and the intensity ratio of the two illumination conditions is evaluated (at least) for the spectral channel with maximum signal.

**[0083]** Fig. 8 shows a set 100 of value documents 1a and 1b, wherein each value document 1a, 1b is illuminated with the first illumination 21 and the second illumination 22, as respectively described with reference to Figs. 3 and 4 above. It is noted that the first illumination 21 and a second illumination 22 are different, for example in terms of their temporal structure.

**[0084]** The set 100 of value documents 1a, 1b comprises a first value document 1a having a first luminescent area 11a and a second luminescent area 12a, wherein both luminescent areas 11a, 12a are located on a surface 10a of the first value document 1a. The set 100 of value documents 1a, 1b further comprises a second value document 1b having a first luminescent area 11b and a second luminescent area 12b, wherein both luminescent areas 11b, 12b are located on a surface 10b of the second value document 1b. The upper left illustration and the upper right illustration show the first value document 1a being illuminated with the first illumination 21 and the second illumination 22, respectively. The lower left illustration and the lower right illustration show the second value document 1b being illuminated with the first illumination 21 and the second illumination 22, respectively.

**[0085]** For both value documents 1a, 1b, the first luminescent area 11a, 11b is configured to emit a first luminescence intensity 31a, 31b, upon illumination with the first illumination 21, and the second luminescent area 12a, 12b is configured to emit a second luminescence intensity 32a, 32b, upon illumination with the first illumination 21 (cf. upper left illustration and lower left illustration showing the value documents 1a, 1b upon the first illumination 21). In particular, for both value documents 1a, 1b, the first luminescent area 11a, 11b is configured to show a first visible luminescent image, e.g., having a first pattern and/or color, with the first luminescence intensity 31a, 31b, upon illumination with the first illumination 21, and the second luminescent area 12a, 12b is configured to show a second visible luminescent image, e.g., having a second pattern and/or color, with the second luminescence intensity 32a, 32b, upon illumination with the first illumination 21.

**[0086]** In addition, for both value documents 1a, 1b, the first luminescent area 11a, 11b is further configured to emit a third luminescence intensity 33a, 33b, upon illumination with the second illumination 22, and the second luminescent area 12a, 12b is configured to emit a fourth luminescence intensity 34a, 34b, upon illumination with the second illumination 22 (cf. upper right illustration and lower right illustration showing the value documents

1a, 1b upon the second illumination 22). In particular, for both value documents 1a, 1b, the first luminescent area 11a, 11b is configured to show the first visible luminescent image, e.g., having the first pattern and/or color, with the third luminescence intensity 33a, 33b, upon illumination with the second illumination 22, and the second luminescent area 12a, 12b is configured to show the second visible luminescent image, e.g., having the second pattern and/or color, with the fourth luminescence intensity 34a, 34b, upon illumination with the second illumination 22.

**[0087]** It is possible that the first illumination 21 and/or the second illumination 22 comprise visible radiation, i.e., within a wavelength range of about 0.38 to 0.75 μm. However, it is possible that the first illumination 21 and/or the second illumination 22 comprise invisible illuminations, i.e., within a wavelength range outside of the visible wavelength range.

**[0088]** For both value documents 1a, 1b, as quality indication a first ratio may be determined, preferably analogous to the method described above, wherein the first ratio represents a ratio of the time-averaged emitted third luminescence intensity 33a, 33b and the time-averaged emitted fourth luminescence intensity 34a, 34b. In particular, the first ratio may be determined based on third and fourth time-averaged luminescence intensities 33a, 33b, 34a, 34b measured with respect the second illumination 22, which for instance is a constant illumination (cf. upper right illustration and lower right illustration showing the value documents 1a, 1b upon the second illumination 22). In this case, the first ratio differs from 1 by less than a specified threshold value. For example, the third luminescence intensity 33a, 33b, also referred to as $I_3$, and the fourth luminescence intensity 34a, 34b, also referred to as $I_4$, are substantially equal or indeed equal during the second illumination 22, such that the following applies: $|I_4/I_3 - 1| < 0.2$, more preferably $< 0.1$. In other words, the first and second luminescent areas 11a, 11b, 12a, 12b, and thus the first and second luminescent images, may appear with approximately the same brightness, upon illumination with the second illumination 22.

**[0089]** For both value documents 1a, 1b, also a second ratio may be determined, wherein the second ratio represents a ratio of the time-averaged emitted first luminescence intensity 31a, 31b and the time-averaged emitted second luminescence intensity 32a, 32b. In particular, the second ratio may be determined based on first and second time-averaged luminescence intensities 31a, 31b, 32a, 32b measured with respect the first illumination 21, which for instance is a pulsed illumination (cf. upper left illustration and lower left illustration showing the value documents 1a, 1b upon the first illumination 21). In this case, the second ratio is substantially equal to a predetermined value different from 1.

**[0090]** In other words, the first and second luminescent areas 11a, 11b, 12a, 12b may appear with a different brightness, upon illumination with the first illumination 21, whereas the first and second luminescent areas 11a, 11b, 12a, 12b may appear with approximately the same brightness or indeed identical brightness, upon illumination with the second illumination 22.

**[0091]** Furthermore, a ratio between the second ratio for the first value document 1a and the second ratio for the second value document 1b is substantially equal to 1, preferably between 0.9 and 1.1, more preferably between 0.95 and 1.05. For example, the second ratio for the first value document 1a differs from the second ratio for the second value document 1b by not more than 10 %, preferably by not more than 5 %. As indicated above, the second ratio results from an intensity difference between the emitted first luminescence intensity 31a, 31b and the emitted second luminescence intensity 32a, 32b, i.e., upon the first (pulsed) illumination 21.

**[0092]** The particular set 100 of value documents 1a, 1b is manufactured, for example by adjusting the amounts and/or concentrations of luminescent material in at least the second luminescent areas 12a, 12b, such that the (first) ratio between the emitted third luminescence intensity 33a and the emitted fourth luminescence intensity 34a for the first value document 1a is approximately identical or indeed identical to the (first) ratio between the emitted third luminescence intensity 33b and the emitted fourth luminescence intensity 34b for the second value document 1b. In other words, the first ratio will be kept as identical as possible for all of the value documents of the set 100 of value documents such that the ratio between the first ratio for one value document and the first ratio for another value document remains substantially equal to 1, preferably between 0.9 and 1.1, more preferably between 0.95 and 1.05.

**[0093]** Preferably, the luminescent materials used for the first and second luminescent areas are stable over time against environmental influences such as UV radiation, chemicals, or solvents. This ensures that the method of determining an authenticity will not only work for newly printed value documents but also for old ones after longer times of usage.

**[0094]** Fig. 9 shows a flow diagram for a method of manufacturing a value document with an authentication feature. In particular, the method may be applied for manufacturing the value document 1 described with reference to Figs. 1 to 4. In the following, the manufacturing method will be described with particular reference to the value document of Figs. 3 and 4. In a step S20, the method comprises providing a value document 1. In a step S21, the method comprises providing a first luminescent material with first luminescent material characteristics. In a step S22, the method comprises providing a second luminescent material with second luminescent material characteristics. In a step S23, the method comprises applying the first luminescent material onto the value document 1 in order to provide a first luminescent area 11 on the value document 1. In a step S24, the method comprises applying the second luminescent material onto the value document 1 in order to provide a second luminescent area 12 on the value document 1. Applying the first luminescent material enables the first luminescent area 11 to emit a first luminescence intensity 31, upon illumination with a first illumination 21, and to emit a third luminescence intensity 33, upon illumination with a second illumination 22 that is different to the first illumination 21. Applying the second luminescent material onto the value document 1 includes adjusting an amount of the second luminescent material applied onto the value document 1, thereby enabling the second luminescent area 12 to emit a second luminescence intensity 32, upon illumination with the first illumination 21, and to emit a fourth luminescence intensity 34, upon illumination with the second illumination 22. The amount of the second luminescent material is adjusted such that a ratio between the emitted third luminescence intensity 33 and the emitted fourth luminescence intensity 34 is substantially equal to 1.

**[0095]** When manufacturing a set of those value documents the above described steps are performed for each value document. After manufacturing a value document the method of determining a quality of the value document is carried out and the result of the determination is used for adjusting the amount of the second luminescent material applied onto a following value document.

## Claims

**1.** A method of determining an authenticity or quality of a value document (1), comprising:

providing a value document (1) having a first luminescent area (11) and a second luminescent area (12, S1);
illuminating the first luminescent area (11) using a first illumination (21, S2);
upon illuminating the first luminescent area (11) using the first illumination (21), measuring a first luminescence intensity (31) that is emitted by the first luminescent area (11, S3);
illuminating the second luminescent area (12) using the first illumination (21, S4);
upon illuminating the second luminescent area (12) using the first illumination (21), measuring a second luminescence intensity (32) that is emitted by the second luminescent area (12, S5);
illuminating the first luminescent area (11) using a second illumination (22), wherein the first illumination (21) has a first temporal structure and the second illumination (22) has a second temporal structure, wherein the first temporal structure is different from the second temporal structure (S7);
upon illuminating the first luminescent area (11) using the second illumination (22), measuring a third luminescence intensity (33) that is emitted by the first luminescent area (11, S8);
illuminating the second luminescent area (12) using the second illumination (22, S9);
upon illuminating the second luminescent area (12) using the second illumination (22), measuring a fourth luminescence intensity (34) that is emitted by the second luminescent area (12, S10);
obtaining the authentication or quality information based on a time-averaged luminescence intensity of the measured first luminescence intensity (31), a time-averaged luminescence intensity of the measured second luminescence intensity (32, a time-averaged luminescence intensity of the measured third luminescence intensity (33) and a time-averaged luminescence intensity of the measured fourth luminescence intensity (34).
wherein the first illumination (21) is defined by a pulsed illumination that includes multiple consecutive first illumination cycles,
wherein the first and second luminescence intensity (31) that is emitted by the first luminescent area (11) and the second luminescent area respectively is measured over a first measuring time interval, the first measuring time interval being at least equal to or larger than one of the first illumination cycles; and
wherein the time-averaged luminescence intensity of the measured first and second luminescence intensity (31) is determined with respect to the first measuring time interval.

**2.** Method according to claim 1, wherein

illuminating the first luminescent area (11) and the second luminescent area (11) using the second illumination (21) is carried out over a second illumination time interval;
measuring the third luminescence intensity (31) and fourth luminescence intensity (31) that is emitted by the first luminescent area (11) and second luminescent area, respectively, over a second measuring time interval, the second measuring time interval being at least equal to or larger than the second illumination time interval;
wherein the time-averaged luminescence intensity of the measured third and fourth luminescence intensity (31), respectively, is determined with respect to the second measuring time interval.

**3.** Method according to one of claims 1 or 2,

wherein the second illumination (22) is defined by a constant illumination; and wherein preferably the second measuring interval is longer than the first illumination cycle..

**4.** Method according to claim 2,

wherein the second illumination (22) is defined by a pulsed illumination that includes multiple second illumination cycles; and
wherein, preferably, the second measuring interval corresponds to at least two consecutive second illumination cycles.

**5.** Method according to any one of the preceding claims,

wherein the first luminescent area (11) is defined by a fluorescent print on the value document (1); and
wherein the second luminescent area (12) is defined by a phosphorescent print on the value document (1).

**6.** Method according to any one of the preceding claims,

wherein the first luminescent area (11) is defined by a first phosphorescent print on the value document (1);
wherein the second luminescent area (12) is defined by a second phosphorescent print on the value document (1);
wherein the first phosphorescent print and the second phosphorescent print comprise different luminescence decay properties with at least 50% different decay times.

**7.** Method according to any of the preceding claims,

wherein the first luminescent area (11) and the second luminescent area (12) are configured to be visible with substantially identical colors, upon being illuminated with the first illumination (21); and/or
wherein the first luminescent area (11) and the second luminescent area (12) are configured to be visible with substantially identical colors, upon being illuminated with the second illumination (22).

**8.** A method of manufacturing a set of value document (1) with an authentication feature, comprising:

providing a set ofvalue documents (1, S20);
for each value document of said set:

1. providing a first luminescent material with first luminescent material characteristics (S21);providing a second luminescent material with second luminescent material characteristics (S22);
2. applying the first luminescent material onto the value document (1) in order to provide a first luminescent area (11) on the value document (1, S23); applying the second luminescent material onto the value document (1) in order to provide a second luminescent area (12) on the value document (1, S24);

wherein the first luminescent area (11) is configured to emit a first luminescence intensity upon illumination with a first illumination and a third luminescence intensity (33) upon illumination with a second illumination (22) that is different form the first illumination;
wherein the second luminescent area (11) is configured to emit a second luminescence intensity (33) upon illumination with said first illumination and a fourth luminescence intensity (33) upon illumination with said second illumination (22);

the method further comprising for at least one value document of said set determining a quality using a method according to one claims 1 to 7 wherein the quality information includes a ratio between the third luminescence intensity (33) and the fourth luminescence intensity (34), wherein in the method of manufacturing said applying the second luminescent material onto one of the value documents (1) of the set includes adjusting an amount of the second luminescent material applied onto the value document (1) using the quality information obtained for said preceding value document, thereby enabling the second luminescent area (12) to emit a fourth luminescence intensity (34) upon illumination with the second illumination (22); wherein a ratio between the third luminescence intensity (33) and the fourth luminescence intensity (34) is between 0.8 and 1.2, preferably between 0.9 and 1.1.

**9.** Method according to claim 8,
wherein applying the first luminescent material onto the value document (1) and/or applying the second luminescent material onto the value document (1) includes using at least one of an offset printing, a flexography printing, an intaglio printing, a screen printing, a letterpress printing or a numbering printing.

**10.** A set of value documents (100), in particular manufactured using a method according to one of claims

8 or 9, comprising:

a first value document (1a) having a first luminescent area (11a) and a second luminescent area (12a);
a second value document (1b) having a first luminescent area (11b) and a second luminescent area (12b);
wherein for each of the first value document (1a) and the second value document (1b):

the first luminescent area (11a, 11b) is configured to emit a first luminescence intensity (31a, 31b), upon illumination with a first illumination (21);
the second luminescent area (12a, 12b) is configured to emit a second luminescence intensity (32a, 32b), upon illumination with the first illumination (21);
the first luminescent area (11a, 11b) is configured to emit a third luminescence intensity (33a, 33b), upon illumination with a second illumination (22) that is different to the first illumination (21);
the second luminescent area (12a, 12b) is configured to emit a fourth luminescence intensity (34a, 34b), upon illumination with the second illumination (22);
a first ratio between the emitted third luminescence intensity (33a, 33b) and the emitted fourth luminescence intensity (34a, 34b) is between 0.8 and 1.2;
a second ratio between the emitted first luminescence intensity (31a, 31b) and the emitted second luminescence intensity (32a, 32b) is less than 0.8 or greater than 1.2.

wherein a ratio between the second ratio for the first value document (1a) and the second ratio for the second value document (1b) is substantially equal to 1, preferably between 0.9 and 1.1.

**11.** Set of value documents according to claim 10, wherein for both the first value document (1a) and the second value document (1b):

the first luminescent area (11a, 1 1b) is defined by a fluorescent print on the value document (1a, 1b); and
wherein the second luminescent area (12a, 12b) is defined by a phosphorescent print on the value document (1a, 1b).

**12.** Set of value documents according to claim 10, wherein for both the first value document (1a) and the second value document (1b):

the first luminescent area (11a, 11b) is defined by a first phosphorescent print on the value document (1a, 1b);
wherein the second luminescent area (12a, 12b) is defined by a second phosphorescent print on the value document (1a, 1b);
wherein the first phosphorescent print comprises a first luminescence decay time and the second phosphorescent print comprises a second luminescence decay time;
wherein the second luminescence decay time is at least 50% longer than the first luminescence decay time.

**13.** Set of value documents according to claim 11 or 12, wherein, upon illumination with the second illumination,
the first luminescent area and the second luminescent area are visible with substantially identical colors and substantially the same brightness.

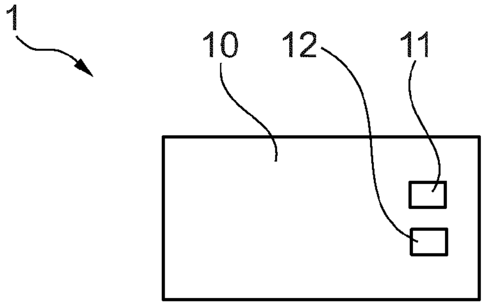



Fig. 1

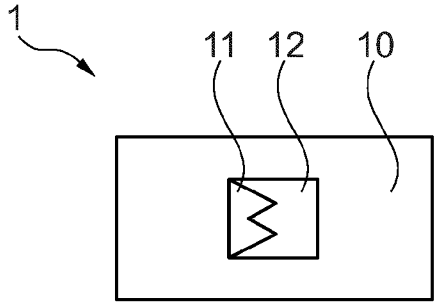



Fig. 2

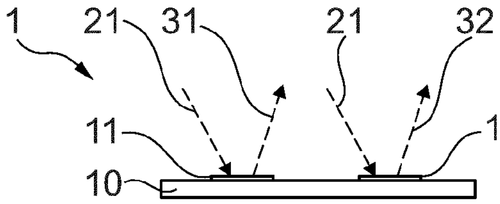



Fig. 3

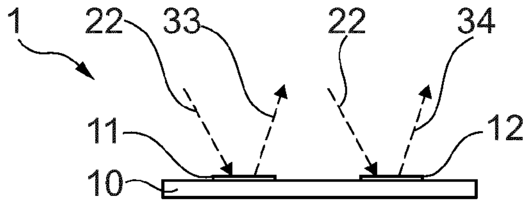



Fig. 4

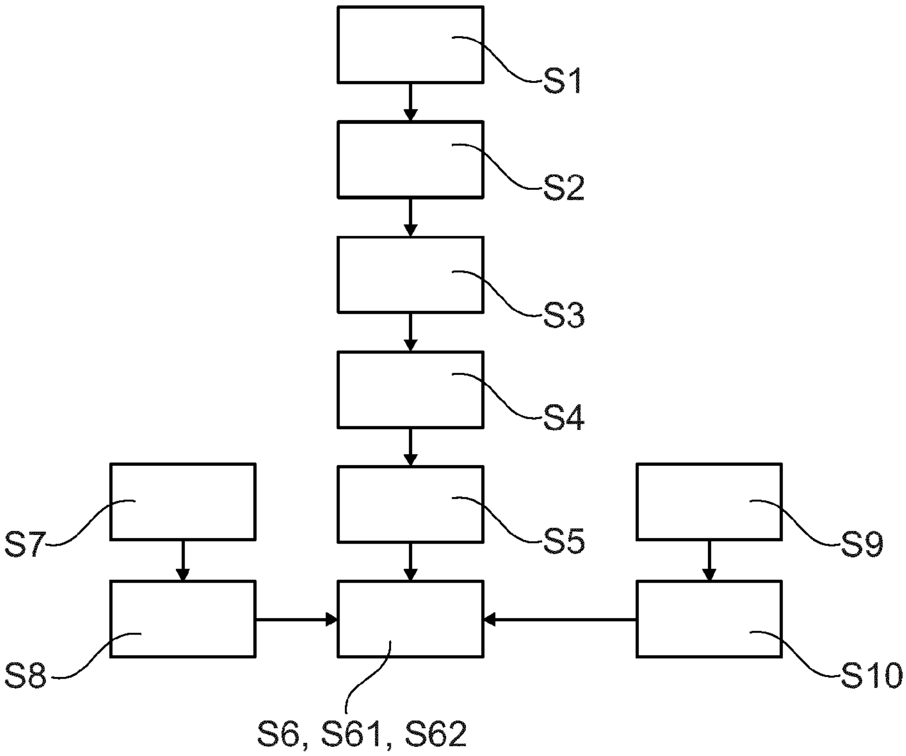
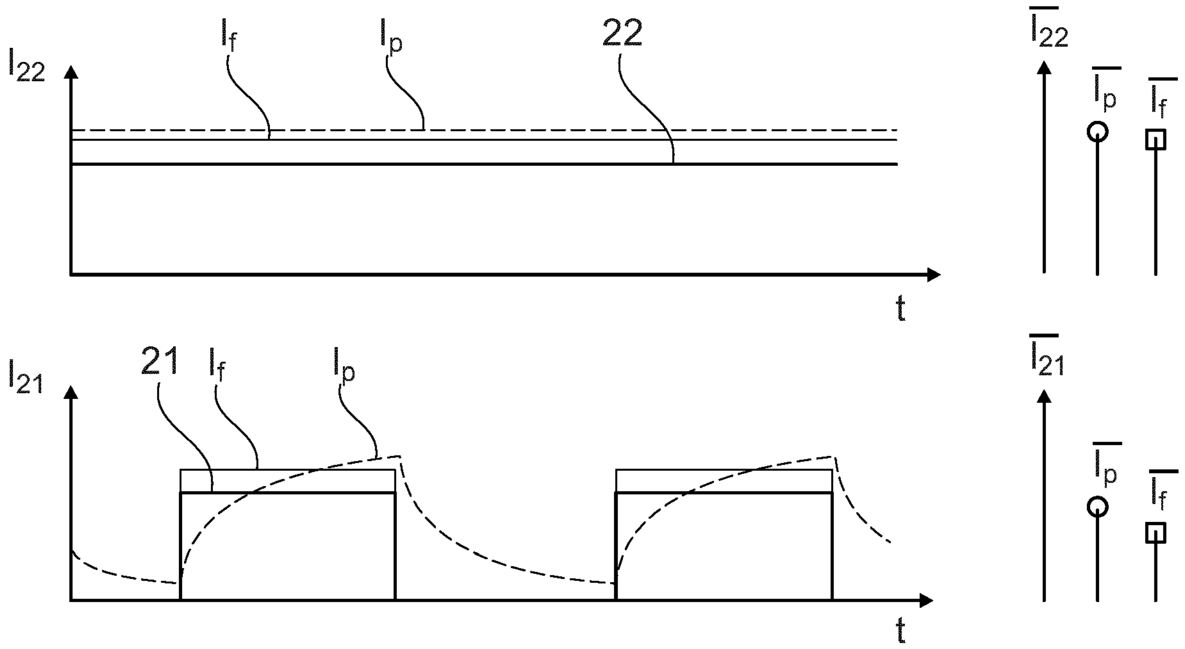



Fig. 5



$I_{22}$
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$I_p$
22
t
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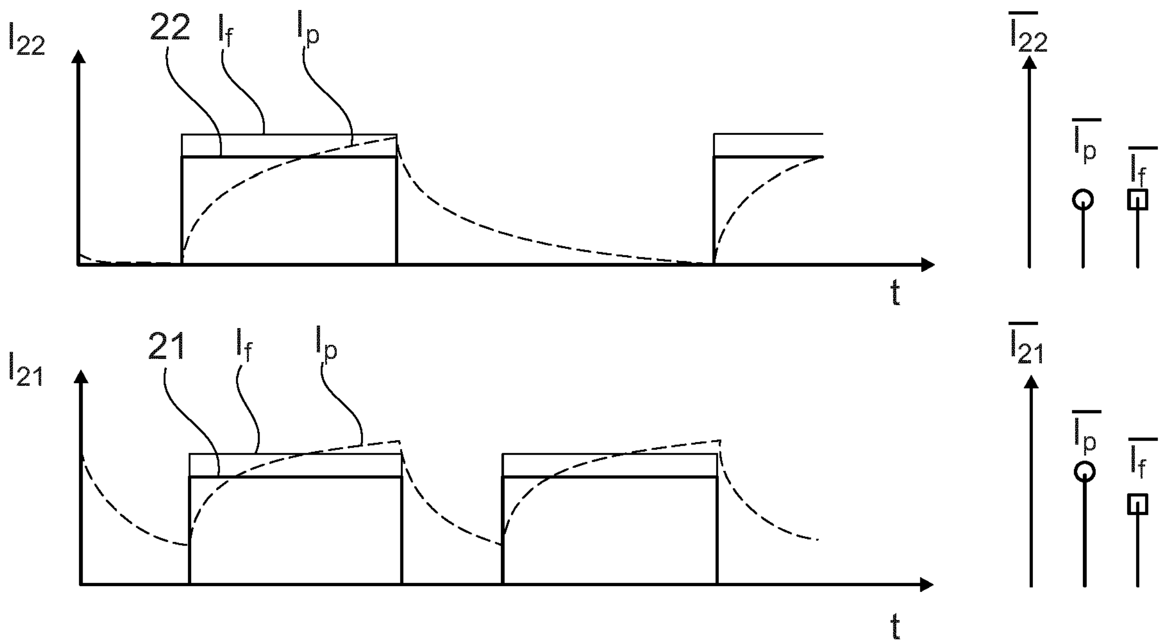
$\overline{I_p}$
$\overline{I_f}$
$I_{21}$
21
$I_f$
$I_p$
t
$\overline{I_{21}}$
$\overline{I_p}$
$\overline{I_f}$


Fig. 6



$I_{22}$
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$I_f$
$I_p$
t
$\overline{I_{22}}$
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$\overline{I_f}$
$I_{21}$
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$I_p$
t
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$\overline{I_f}$


Fig. 7

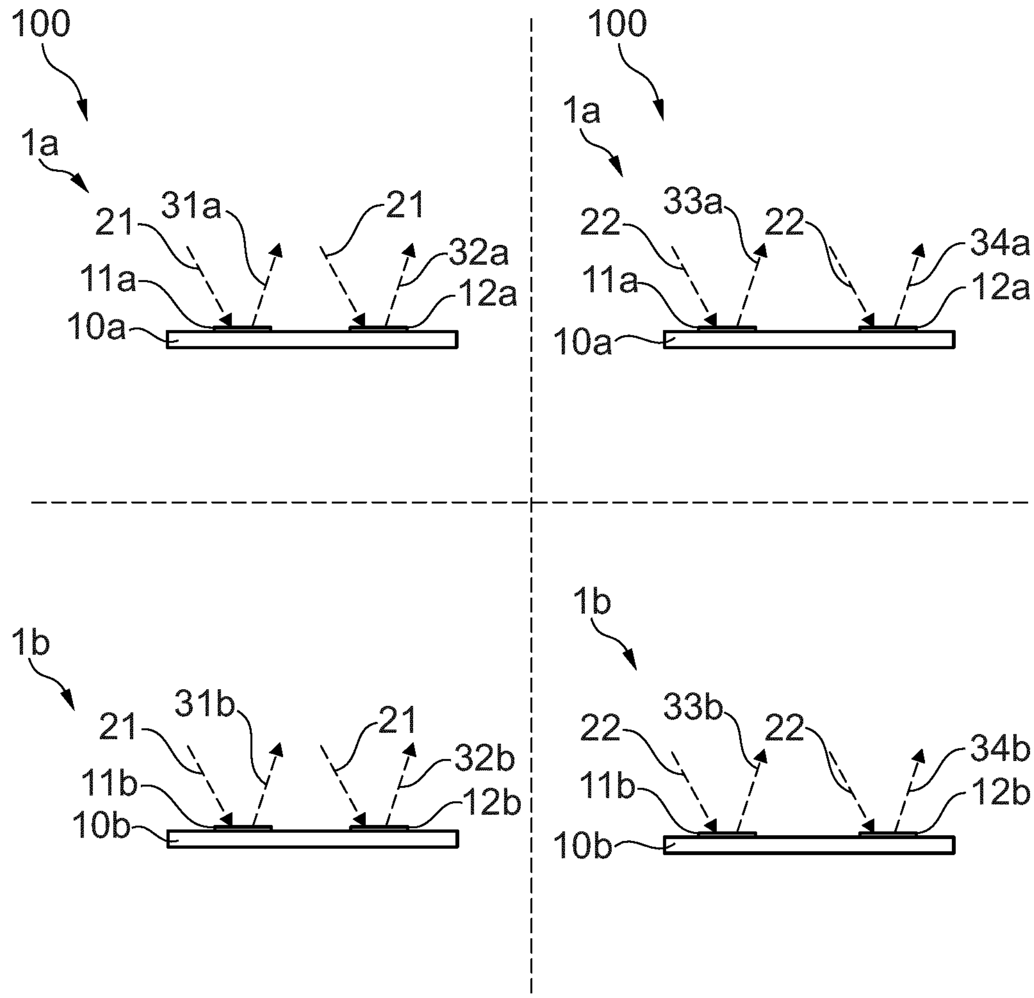
100
1a
21
31a
21
32a
11a
12a
10a
100
1a
22
33a
22
34a
11a
12a
10a
1b
21
31b
21
32b
11b
12b
10b
1b
22
33b
22
34b
11b
12b
10b

Fig. 8

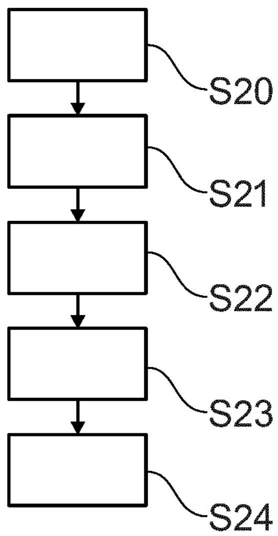
S20
S21
S22
S23
S24

Fig. 9

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Application Number
EP 24 02 0024

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The present search report has been drawn up for all claims

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| The Hague | 6 June 2024 | Seifi, Mozhdeh |

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