(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
12 May 2016 (12.05.2016)

WIPO | PCT

(10) International Publication Number
WO 2016/072879 A2

(51) International Patent Classification:
G06K 19/06 (2006.01)

(21) International Application Number:
PCT/RU2015/000676

(22) International Filing Date:
15 October 2015 (15.10.2015)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
62/076,813 7 November 2014 (07.11.2014) US

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *without international search report and to be republished upon receipt of that report (Rule 48.2(g))*

WO 2016/072879 A2

(54) **Title**: METHOD OF PROTECTING PHYSICAL OBJECTS INTENDED FOR IDENTIFICATION AND AUTHENTICATION OF PROPRIETARY INFORMATION

(57) **Abstract**: The invention relates to the protection against the forging of credit cards, passports, identity certificates and other documents of strict accountability. The invention allows to resolve the problem of the state of protection against forgery of payment cards and documents while maintaining simplicity in the production of means of protection against forgery applied as protection of physical objects, particularly payment cards, passports, identity certificates and other types of proprietary information. The method of protection against the forging of physical objects consists in the inclusion in the matrix of the object to be protected or putting on its surface substances capable of, under the influence of electromagnetic radiation of from 0.1 to 10 nm wavelength (x-ray range) or of a from 10 to 400 nm wavelength (ultraviolet range), or a wavelength of from 400 nm to 780 nm (visible range), or a wavelength of from 780 nm to 59 um (infrared range), or under the influence of an electric field to luminesce (radiate) in the visible of infrared range; and the determination of the presence of coordinates, dimension, vending angle of radiating points is brought about with the aid of scanners, semiconductor matrices, etc. Furthermore, the digital graphic representation of the distribution of luminescing points (forming a pattern) is compared with a local or distant data base of patterns of protected objects established beforehand with the aim of consequent identification of protected objects.

Method of protecting physical objects intended for identification and authentication of proprietary information

Technical Field

The invention relates to the protection against the forging of credit cards, passports, identity certificates and other documents of strict accountability.

Background Art

At the present time direct financial losses due to forgeries of credit cards amount to hundreds of millions of dollars. In 2013, in 24 industrialized countries the losses due to cyber crime, according to data of SYMANTEC CORPORATION, amounted to 388 billion dollars with direct losses amounting to 114 billion dollars. That is connected with that the contemporary level of development of electronic computing, analytical and duplicating technologies allows with comparatively low expenses to compromise existing modes of protection of physical carriers of proprietary information with the aim of subsequent imitation of the physical presence of information carriers or the reproduction of such information on a similar carrier.

Known are various means of written orders for goods and services in the retail market intended for accomplishing off-line payments.

The most widespread form of such means of payment is the credit card. Credit cards can be divided according to the way of interaction with the computing device, into contact and contact-less ones, which also differ according to ways and means of preventing physical attack.

A plastic card is a plate of standard dimensions (85.6 x 53.9 x 0.76 mm) made of a special plastic resistant to mechanical and thermal influence. One of the basic functions of the plastic card is the ensuring of identification and authentication of its user as the subject of the payment system. For that purpose the plastic card is marked with the logotype of the emitting bank and payment system servicing that card, the name of the card's owner, his account number, period of validity of the card, etc. Besides that, the card can have a photograph of the owner and his signature. Alphabetical and digital data – name, account number, etc. – can be embossed, i.e. printed in raised script.

There are various ways of protecting credit cards in carrying out PIN operations applied in operations with contact cards.

Known is the mode of protecting information on the plastic card consisting of the placing on the surface of the plastic card a restraining magnetic band containing one, two or three

grooves with data for identification by the emitting bank using the PVV (PIN Verification Value) method.

Known is the mode of distribution of micro-diagrams on credit cards of the ICC type (integrated electronic-chain cards). Such micro-diagrams (in most cases) contain a microprocessor and memory module with an intended operational system controlling the mechanism and access to objects in its memory. The purpose of ICC cards is a one- and two-factor authentication of the users, protection of key information and carrying out cryptographic operations in a confidential environment. Cards with an integrated operational system (e.g. JCOP or MULTOS) and using complex logic in carrying out PIN operations are called SMART cards. Such cards, besides symmetrical cryptography (AES, DES), for protection against physical attack, can also use asymmetrical cryptography (RSA), algorithms of the infrastructure of open keys (PKI), have instrumental generators of chance numbers.

Known is the way of putting ultraviolet color on the card in its production.

Known is the mode of protecting bank notes, securities and documents with the aid of anti-Stokes luminophores (Patent No. 2137612).

In that mode, on the object to be protected the protective material, an anti-Stokes luminophore, is put polygraphicly or otherwise (composed of a dye, glue, inks, etc.). The resulting anti-Stokes luminophore mark is detected (illuminated) with a simple gallium arsenide detector. However, such a way does not fulfill the protection of physical objects -carriers of proprietary information, against being compromised.

The vulnerability of contact cards:

1. The magnetic band is not a reliable means of protection because most devices for reading magnetic cards (readers), also has the function of recording, are supplied in a complex with a special security program and are widely spread in the open market. The broad availability of such devices makes the magnetic band a vulnerable means of protection against physical attack even by a malefactor without any special technical characteristics. The fact that many ATMs[1] have become morally antiquated and do not have functions of reading other means of protection against physical attack (such as the distribution of micro-diagrams on the body of the card) makes that kind of attack most available.

2. The distribution of micro-diagrams and chips on the body of credit cards as a means of protection is also frequently attacked by malefactors. In first place, that is connected with that the mechanisms of reading SMART and ICC cards are widely spread and in the majority of cases have the function of reading as well as of recording. However, many smart cards are protected from direct copying because various parts of its memory are not accessible for reading

up to the carrying out of a certain cryptographic or calculating operation, or generally, they are inaccessible for reading at the physical level and are used as a physical argument of the operation (operand) for opening or closing other memory modules (on the principle of a black box). In that case, possible are the following kinds of attack:

A. A raid on the vulnerabilities of SMART cards. That is assisted by a practically full openness of all of the applied algorithms.

B. Differential analysis of feeding – assessment of oscillograms of the electric energy used by a smart card at the moment of fulfilling of the crypto-algorithm.

C. Physical breaking in – acquiring access to electrical chains of a smart card after the chemical removal of protective layers from the crystal. It allows to carry out an analysis of the smart card's mechanism, and to be connected to it with the aid of microelectrodes (that method can be applied only on long-term access to the victim's card).

D. Unusual conditions of smart card exploitation -- for instance, a too high temperature regime, too high tension and frequency of the signal at the contacts, etc. That can cause knock-outs in algorithms with subsequent gaining access to information.

3. Ultraviolet color is widely spread and is widely accessible. So, the absolute majority of ATM and POS terminals do not use ultraviolet identification.

The basic ways of protecting credit cards when carrying out PIN operations, applied in operations with contact-less cards:

1. Deliberate limiting of the action radius of the active part of the system (of the reading mechanism) to a few centimeters.

2. Application of special protocols of data transfer – ISO/IES 14443.

3. Application of dynamic CVC / CVV (card verification code / card verification value) eliminating the possibility of theft of data and further use for illegal purchases at on-line e-shops.

4. Methods of dynamic card authentication (CDA – Combined Dynamic Data Authentication / Application Cryptogram Generation).

5. Recommendations to users to protect their contact-less cards in a special casing.

The most widely known vulnerabilities of contact-less cards:

1. Attack of the relay attack type: An authorized reader (a reader registered at some servicing bank of the payment system) in an unapproved way, i.e. without the client's consent, initiates and carries out payment operations through the client's contact-less card.

2. Attacks of the pick-pocket theft type: an unauthorized reader (a reader not registered at any servicing bank of the payment system) uses for the carrying out of operations not approved

by the card's owner with the aim of utilizing data obtained in the "card – reader" dialogue for the making of a false card and implementing it in payment operations at authorized terminals.

3. Attack in which there takes place the taking over of data from the "card – reader" dialogue, particularly of data transferred through the card, with the aim of using the obtained information for forging a card or committing fowl play of theft of identification data of the card's owner.

4. Attacks of the data modification type: the malefactor tries to modify data in the "card – terminal" dialogue in a way convenient for him; for instance, upon agreement with the card's owner the swindler can reduce the volume of operations and/or modify the card's reply to the terminal, requiring authorization in an off-line regime.

5. Attacks of the man-in-the-middle type: the swindler (more exactly, his technical means) is between the card and the reader, stealing the "card – reader" dialogue with the aim to modify it in a way convenient for him.

6. Attacks of the Radio Frequency Analysis (RFA) type: An attack aimed at obtaining the meaning of the card's secret cryptographic key with the aid of measuring the card's magnetic field along with its micro-diagram.

Conclusion: Identification and authentication can be considered to be the basis of technical program means of the safety of information. The credit card is a fundamental physical instrument and carrier of the sum of data about the payment system's subject.

However, there exists a multitude of ways of illegally obtaining access to information in plastic card information carriers – beginning with the installation of illegal equipment on an ATM and ending in high-level attacks at an HSM (hardware security module).

Disclosure of Invention

The claimed method of protecting physical objects intended for identification and authentication of proprietary information (payment cards, passports, identity certificates, rated account data, other types of personal data) allows the protection of access to a user's account (accounts) even in the case of attack at other vulnerable points of the payment system – e.g. a distant attack at an HSM, since even in the case of a full compromising of data of the payment card (including the visual pattern in the form of a perceptive hash mark or other form suitable for reading and identification by the computer system and the PIN code), their intended misuse for reproduction or imitation of the compromised payment card remains impossible.

The claimed method provides that on the surface of the product or in its composition there are included special substances, then under the influence of electromagnetic radiation or an

electric field there can be brought about luminescing (radiation) in the visible or infrared range, and the control of authenticity is carried out with the aid of comparing the coordinates of radiation points of the substance (pattern) of the protected object with a local or distant data base of patterns of protected objects.

The radiating compounds can be included into thy matrix of the protected physical object in such a way that fragments of the radiating substance are distributed in the matrix in a random chance way.

The radiating compounds can be put on the surface of the protected physical object in a composition of varnishes or resins or paints, and the fragments of the radiating substance are distributed in a random chance way.

The radiating compound can be included in the composition of a polymer film, and the film is laminated onto the surface of the protected physical object.

In the capacity of a radiating substance can be applied anti-Stokes compounds.

In the capacity of a radiating substance can be implemented quantum points.

The excitation of the radiating compound can be brought about by electromagnetic radiation of a wavelength of from 780 nm to 59 μm (infrared range).

The excitation of the radiating compound can be brought about by electromagnetic radiation of a wavelength of from 10 to 400 nm (ultraviolet range).

The protected object can be placed in a lead-in device in which there are added up the coordinates of radiation points and there is established a digital graphic representation of the distribution of the points – the pattern.

The pattern of the protected object can be compared with a local or distant data base of patterns of protected objects, established beforehand with the aim of subsequent identification of the protected objects.

A distant or local computer system, on the basis of the coincidence of signs of the pattern of the protected object can establish the identity of the protected object with one of the protected objects the pattern of which is found in the data base, or it reveals an absence of such. At the same time, for the comparison of signs there can be applied various algorithms of comparison and analysis of representations as a whole or in part.

Brief Description of Drawings

Fig. 1 illustrates mechanisms summation of the excitation energy of the ions.

Fig. 2 is schematic drawing of possible processes occurring in a three energy level system.

Fig. 3 illustrates energy transfer mechanisms between the ion donating energy (sensitizer) and the ion accepting energy (activator).

Fig. 4 illustrates experimental demonstration of the spectral narrowing in $YF_3:Er^{3+}$.

Fig, 5 illustrates input power dependence of the emission from different energy levels as a result of up-conversion processes under excitation at 1540 nm observed in $Cs_3Lu_2Cl_9:Er^{3+}$ (1%).

Fig. 6 is Table in which are shown The resulting power dependence of the population of the energy levels Ni for the different cases.

Fig. 7 illustrates ASL excitation spectra.

Fig. 8 illustrates emission up-conversion spectra under 980-nm light excitation Y_2O_2S (Yb,Er) (green).

Fig. 9 illustrates emission up-conversion spectra under 980-nm light excitation Y_2O_3 (Yb,Er) (red).

Fig. 10 illustrates emission up-conversion spectra under 980-nm light excitation Y_2O_2S (Yb,Tm) (blue color)

Fig. 11 illustrates emission up-conversion spectra under 980-nm light excitation (Yb,Tm) (white)

Fig. 12 illustrates SEM image Y_2O_2S (Yb,Er) (green) (1 cm = 10 μ).

Best Mode for Carrying out the Invention

In accord with the technical solution, into the composition of the material of a credit card or on its surface there are introduced substances capable of, under the influence of electromagnetic radiation of a wavelength of from 0.1 to 10 nm (x-ray range), or of a wavelength of from 10 to 400 nm (ultraviolet range), or of a wavelength of from 780 nm to 59 μm (infrared range) or under the influence of an electric field, luminescing (radiating) in the visible or infrared range.

Example 1 **Anti-Stokes luminescence**

In such indices as radiation intensity, Chemical and Physical Stability most preferred for the protection and identification of credit Cards are anti-Stokes compounds. On such parameters as the intensity of the radiation resistance to destructive factors (chemical, radiation, etc.), the most preferred grain compound for the protection and identification of credit cards are anti-Stokes connection.

Anti-Stokes phosphors convert the long-wave radiation of low energy quanta into short-wave radiation rays that have a higher energy. Hence, at is process there is a summation of rays;

two or more lower energy quanta produce a quantum of a higher energy. For example, these phosphors convert infrared radiation into visible light.

Historical background

According to Stokes' rule, the emission wavelength of luminescence is longer than the excitation wavelength. In this regard, the luminescence in the visible spectrum when excited in the IR range is called "anti-Stokes" or "upconversion phosphors" (hereinafter ASL).

The first reports of anti-Stokes luminescence of zinc and cadmium sulfides appeared in 1959 However, the observed luminescence intensity was very low, both because of the low efficiency of the process and because of the weak absorption of infrared radiation base material. Simultaneously N. Bloembergen proposed quantum counter based on visible luminescence occurring at consecutive absorption of two photons of different wavelengths by ions of rare earths.

In 1966 V.V. Ovsyankin and P.P. Feofilov found that the visible luminescence of Er^{+3}, Ho^{+3} and Tm^{+3} in barium fluorides increases by almost 2 orders of magnitude the introduction based phosphor ions Yb^{+3}. The same effect was observed by F. Auzel in sodium tungstate .

Anti-Stokes phosphors have stopped being exotic since the development of synthesis of oxysulfide compounds.

Elementary processes involved in the ASL processes include ground state absorption (GSA), and the excited states absorption (ESA), radiative and radiationless decay and energy transfer processes (ETU). Energy transfer can occur between different ions, and among the same kind of ions (known as migration or diffusion of energy). In addition, they can be resonant or phonon- assisted. The rate of nonradiative multiphonon decay depends on the number of phonons required for relaxation to the next lower level.

It is known that the relaxation rate decreases approximately exponentially with the value of the energy gap between the levels, in other words, the number of phonons emitted. The phonon-assisted transmission rate also depends exponentially on the energy difference.

To explain the phenomenon of ASL of rare earth ions several mechanisms are proposed:

Successive photon absorption - Figure 1a

The first low-energy absorption in the quantum ground state of the rare earth ion-activator. The second photon is absorbed by the excited states of the rare-earth ion with the transfer to the second higher excited level. The lifetime of the first excited level must be long enough in order that there be no radiation emitted from that start before the arrival of the second quantum.

Cooperative luminescence - Figure 1b.

Unlike sequential mechanisms in this process two ion sensitizers simultaneously transmit the excitation energy of the activator, translating it into the emitting state.

Successive sensitization - Figure 1c.

The mechanism is similar to the previous one, only photon-absorbed energy is transferred to the sensitizer and the activator in the neighboring lattice site, translating it into the first excited state (1 photon) and from the first to the higher emitting states (2 photons).

Systematic studies have shown that in most of the phosphors with rare earth ions (Er^{3+}, Ho^{3+}, Tm^{3+} together with Yb^{3+}) materialized are processes of successive sensitization considered by F. Auzel.

Cooperative sensitization reliably observed only for the Yb^{3+}—Tb^{3+} pair, for which there is absent a once excited state of the radiating ion, close in energy to the excited state of the sensitizing ion.

Similar processes of summation of elementary excitations occur in a number of laser crystals types of glass containing rare earth ions.

Up-Conversion Mechanisms

Up-conversion is a special case of a complex combination of excitation and luminescent processes in a system containing at least three energy levels. Generally, the kinetics of such processes can be described by rate equations, through which the temporal change of the population density of the involved energy levels is formulated. Two main up-conversion mechanisms were presented, (1) ground state absorption followed by excited state absorption (GSA/ESA) and (2) energy transfer (GSA/ETU). Beside these processes, other processes also occur in a system consisting of three energy levels as assumed for the following calculations and depicted in Fig. 2.

Fig. 2 is schematic drawing of possible processes occurring in a three energy level system:

(a) Ground state absorption (GSA) (b) Relaxation (c) Excited state absorption (ESA); (d) Energy transfer up-conversion (ETU); (e) Cross-Relaxation; Cooperative processes: (f) excitation and (g) relaxation

Besides excitation (de-excitation) or in the ground state absorption (GSA), the spontaneous decay and in the excited state absorption (ESA), there contribute to energy transfer processes between the various ions, such as the transfer of energy with the up-conversion (ETU), cross relaxation, cooperative excitation and relaxation, which occur with varying probabilities, and change density of the population of the energy levels, N_i.

Energy transfer up-conversion is defined as a process, whereby the ion accepting the energy is afterwards in a higher excited state than the donator before the process. If this is otherwise, the process is

called cross relaxation, the inverse of energy transfer up-conversion. Less efficient are cooperative processes such as cooperative excitation (enhancing up-conversion efficiency) and the respective inverse process, cooperative relaxation (reducing up-conversion efficiency). Generally, losses caused by energy transfer, which are therefore dependent on the concentration of the dopant, are called concentration quenching.

The population density of the i-th energy level is defined to be N_i. Changes in the population of the ground level N_0 can be caused by ground state absorption, where the change in the population is proportional to the population of the level and a term, describing the probability for this transition, G_{01}. The population of the ground state can be enhanced by relaxations from the higher energy levels with the Einstein coefficients as probabilities for this process. Also more complex processes, such as energy transfer up-conversion (ETU), cross relaxation (CR), cooperative excitation (CE) and cooperative relaxation (CooR), influence the population of the ground state. This kind of description can be developed for the population of each level, which leads to the rate equations for a three level system.

Ground and Excited State Absorption

The probability of a transition within a free ion induced by incident radiation can be derived by time-dependent perturbation theory. For electric dipole transitions (when the electric field given by the incident radiation interacts with the electric dipole moment of the absorbing center) the probability can be expressed as

$$G_{if} = \frac{\pi}{3n\epsilon_0 c_0 \hbar^2} I \; |\boldsymbol{\mu}_{if}|^2 \, \delta(\omega_0)$$

where ω_0 is the angular frequency, $\boldsymbol{\mu}_{if}$ is the matrix element of the electric dipole moment, I is the intensity of the incident radiation, n is the refractive index of the absorbing medium, e_0 is the permittivity in vacuum, c_0 is the speed of light in vacuum, and $\hbar$ is Planck's constant, h, divided by 2π. The Dirac delta function $\delta(\omega_0)$ indicates the selectivity of the transition on the frequency of the incident radiation. To describe realistic processes this function can be replaced by the line shape function $g(\omega)$. From this it follows that (1)the transition probability is dependent on the intensity of the incident light and (2) since $|\boldsymbol{\mu}_{if}| = |\boldsymbol{\mu}_{fi}|$ the probability for stimulated emission is the same as for absorption.

Energy transfer processes

In addition to stimulated and spontaneous transitions, some up-conversion processes rely on energy transfer processes between different ions. The ion donating its energy is called the sensitizer (S), the ion receiving the energy is the activator (A). These processes are depicted in Fig. 3.

A first distinction can be made between radiative and non-radiative energy transfer. The probability of radiative energy transfer depends on the spectral overlap between the involved transitions:

$$w_{ET}^{nr} = \frac{2\pi}{\hbar}\frac{\int g_S\, g_A d\nu}{d_S d_A}\sum_{l_1,l_2}|C_{l_1 l_2}\langle S^*||U^{l_1}||S^0\rangle \times \langle A^0||U^{l_2}||A^*\rangle|^2$$

The probability of a radiative energy transfer depends on the absorption cross section of the activator σ_A, the lifetime of the excited state of the sensitizer τ_S, the spatial distance R of the involved ions and the spectral overlap (given by the integral over the line shape functions $g(v)$). Due to the dependency on the spectral overlap the probability is high for identical ions and identical involved energy levels. When measuring the lifetime of a given transition, this effect can cause distortions to higher lifetimes, since emitted photons are trapped by other ions (photon trapping).

Fig. 3 illustrates energy transfer mechanisms between the ion donating energy (sensitizer) and the ion accepting energy (activator). These transfers can be radiative or non-radiative (if emission of photons is involved or not), and resonant or phonon-assisted (if the energy submitted by the sensitizer is exactly the energy received by the activator or if phonons are necessary to compensate insufficient spectral overlap).

A further distinction can be made between energy transfers where the energy donated from one ion compared to the energy accepted by the second ion is the same (resonant process) or not (phonon assisted energy transfer).

For resonant, non-radiative energy transfers the probability for energy transfer can be written as:

$$w_{ET}^{nr} = \frac{2\pi}{\hbar}\frac{\int g_S\, g_A d\nu}{d_S d_A}\sum_{l_1,l_2}|C_{l_1 l_2}\langle S^*||U^{l_1}||S^0\rangle \times \langle A^0||U^{l_2}||A^*\rangle|^2$$

where d_S and d_A are the degeneracies of the excited state of the sensitizer and the ground state of the activator respectively. The integral over the line shape functions of the emission of the sensitizer g_S and the absorption of the activator g_A is a measure of the overlap of the involved energy levels. The sum is similar to that in the Judd-Ofelt approach, where the constants C_{l1l2} are analogous to the intensity parameters Ω_t and the reduced matrix elements describe the transitions exactly as in the Judd-Ofelt theory. With this description, resonant non-radiative energy transfer processes are described within a single mathematical form, regardless of the kind of interaction (electric dipole or magnetic dipole or higher orders).

The probability for this energy transfer is zero if the overlap integral of the emission of the sensitizer and absorption of the activator vanishes. But even in this case energy transfers have been observed experimentally, which is explained by the inclusion of phonons, which conserve the energy. Thus on the basis of phonon assisted energy transfer, an exchange of energy is possible, even if the spectral overlap integral is zero. Miyakawa and Dexter showed that the probability of phonon assisted energy transfer can be written as:

$$w_{ET}^{nr,pa} \propto W_{pa0}\, e^{-\beta \Delta E}$$

where W_{pa0} and β are constants depending on the host material. The crucial point is the dependency on the energy gap in a very similar way as found for the energy gap law. From this it follows that phonons can have both a positive influence on energy transfer mechanisms, which are the basis of some up-conversion mechanisms, and detrimental effects in the form of assistance to undesired non-radiative relaxations.

Dependence of Emitted Light on Input Power

Up-conversion is a non-linear effect in relation to the intensity of the incident radiation. Generally for non-linear optical processes, the emitted intensity I_{em} depends on the intensity of the incident light I_{in} via a power law, where the exponent n equals the number of required photons to excite the emitting state:

$$I_{em} \propto I_{in}^{n}$$

Fig. 4 illustrates experimental demonstration of the spectral narrowing in $YF_3:Er^{3+}$. The higher the order n of the up-conversion process, the more distinctive the line shape of the $^4I_{15/2} \rightarrow {}^4I_{13/2}$ absorption reveals .

This is only true for low feeding powers, otherwise the energy conservation law would be violated. In a double-logarithmic depiction of emitted intensity versus incident intensity this saturation equals a reduction of the slope n. Power dependent measurements performed by Gamelin et al. on $Cs_3Lu_2Cl_9:Er^{3+}$ (1%) under excitation at 1540 nm for different emissions due to up-conversion processes are shown in Figure 2 (f). All emission curves level out at higher feeding powers.

The theoretical dependency of up-conversion emission on the feeding power has been derived by Pollnau et al. by the numerical solution of rate equations, similar to the ones given at the beginning of this chapter. In these calculations a model is assumed with four energy levels beside the ground state, as depicted in Figure 4. All loss mechanisms have been neglected, so that the model contains the excitation by feeding constantly with infrared light (GSA), relaxations only to the ground state or the

next lower level and the up-conversion processes (ESA and ETU). These rate equations have been solved numerically with respect to

1. The dominance of up-conversion. If luminescence dominates over up-conversion as the depletion mechanism of intermediate states, the influence of up-conversion is regarded as small. This is in contrast to large up-conversion rates, where up-conversion is the major depletion mechanism.

2. The dominant decay route. The decay can be mainly to the next lower lying state, or to the ground state.

3. The fraction of absorbed feeding power, which is assumed to be large or small.

Fig, 5 illustrates input power dependence of the emission from different energy levels as a result of up-conversion processes under excitation at 1540 nm observed in $Cs_3Lu_2Cl_9:Er^{3+}$ (1%).

The resulting power dependence of the population of the energy levels N_i for the different cases are listed in Table on Fig. 6. Since the luminescence from a given level can be assumed to be directly proportional to the excited population N of the level, this directly relates to the slope predicted for the double logarithmic depiction of emitted intensity of an emission from a given level versus feeding power.

The power dependence of the emission intensity of up-converted light on the incident intensity can be experimentally determined for a given emission by photoluminescence measurements under varying input power. Measuring external quantum efficiency of a solar cell with the up-converter applied to the rear under varying input power, the resulting signal contains the emission from all energy levels simultaneously.

Up-conversion efficiency

From the discussion of the emitted up-conversion intensity on the input power it follows that also the up-conversion efficiency must be dependent on the input power. Generally, the efficiency of a luminescent process is defined as the ratio between the desired radiative de-excitation of a certain energy level and all other possible radiative or non-radiative de-excitations. This has already been formulated for spontaneous de-excitation in the equation:

$$\eta_{if} = \frac{A_{if}}{\sum_k A_{ik}^{rad} + A^{nr}}$$

For the expression of the efficiency of up-conversion processes this is more complicated, since more than one transition is involved.

Table on Fig. 6 illustrates dependency of the population of an energy level Ni on the feeding power. The slopes depend on the dominance of up-conversion processes compared to

conventional luminescence, the dominant up-conversion (ESA or ETU) has its in the depletion mechanism, whether the relaxation more likely to the next lower level or directly to the ground state and the absorption properties of the sample.

The main properties of the anti-Stokes phosphors

Efficiency

It has been noted already that the brightness of ASL is proportional to the square (or cube) of excitation intensity. Saturation is not reached even at an excitation density of 170 W/cm^2, when the efficiency of the green emission reaches 7.3%, and that of the red one - 15%. At moderate excitation densities the energy efficiency does not exceed 1%.

Excitaion spectra

Luminescence excitation spectra are determined mainly by the absorption of infrared radiation by the ytterbium ion, so the maximum excitation of phosphors occurs near 975 nm. This is true for all the phosphors with Yb^{3+} as a sensitizer. However, the lattice of the base has a great influence on the transition probabilities in the process of emission and on the limit of conversion efficiency. In this regard, the excitation spectra differ slightly depending on the type of base of the phosphor. In Fig. 7 is shown the luminescence excitation spectra for lanthanum oxysulfide and sodium yttrium tetrafluoride; It also shows the emission spectrum of the diode of gallium arsenide doped with silicon.

Fig. 7 illustrates ASL excitation spectra: 1 - $NaYF_4$ (Yb,Er); 2 - La_2O_2S (Yb,Er); 3 - the emission spectrum of the GaAs—Si diode; 4 – the emission spectrum of the laser diode IDL100M-980.

It is evident that the emission GaAs - Si can be utilized at not more than 30% in the case of fluorides, and at 60% in the case of oxysulfide. Other possible sources of excitation that should be noted are incandescent (especially "iodine") and high pressure xenon arc lamps, a significant portion of the radiation which is in the infrared region.

Incandescent lamps with an iodine cycle of approximately 3% of the total power falls on the IR radiation in the 900-1000 nm range, about as much as is found in visible spectrum radiation. Using even a portion of this energy to convert into visible radiation would increase markedly incandescent light output.. The complexity of solving such a problem is that the ASL absorb appreciably in the same range where they emit. Therefore, a phosphor layer coated on the lamp bulb, will greatly attenuate radiation. Furthermore, the surface of the lamp bulb is heated to 200°C, wherein the quenching of the luminescence of the majority of ASL takes place.

Emission spectra

The emission spectra of the developed ASL of green, red, blue and white light were obtained upon excitation of phosphors by laser radiation with a wavelength of 980 nm, produced by the laser diode IDL100M-980 by "SRI" Polyus "," Moscow.

Excitation spectra are shown in Figures 8, 9, and 10, and they consist of narrow bands corresponding to transitions in ions of erbium (green and red) and thulium (blue). Fig. 8 illustrates emission up-conversion spectra under 980-nm light excitation Y_2O_2S (Yb,Er) (green). Fig. 9 illustrates emission up-conversion spectra under 980-nm light excitation Y_2O_3 (Yb,Er) (red). Fig. 10 illustrates emission up-conversion spectra under 980-nm light excitation Y_2O_2S (Yb,Tm) (blue color).

The ratio of the intensity of bands and their widths depend to some extent on the basis of the phosphor. For fluorides, the characteristic emission spectra have a predominant share of the emission in the green region. For REM oxide and oxysulfide systems, conversely, there is predominance of band intensities in the red part of the spectrum.

A characteristic feature of phosphors containing ytterbium and erbium is a change in emission color depending on the excitation conditions. This is due to the fact that the red bar erupted in proportion to the intensity of the excitation level of 2.5, and green - the square of the intensity of the exciting radiation. Under pulsed excitation emission the color also depends on the duration of the pulses of IR excitation. For short pulses (~100 μs) dominates the green bar, and at long (~500 μs) – the red one. In principle, it is possible to obtain any color using a mixture of three phosphors with blue, green and red light, and combining the excitation conditions (intensity and duration).

Designed has also been a single-component phosphor of white color luminescence, Figure 11, which illustrates emission up-conversion spectra under 980-nm light excitation (Yb,Tm).

1. The white color luminescence can be obtained by mixing in suitable proportions the three phosphors of red, green and blue luminescence, as proposed, for example, Patent RU2333108, Petrik Viktor I. " A method of identification and protection of tax stamps, banknotes, securities, documents, articles and the latent image carrier as the identification security mark" 18.09.1998;

2. However, with small amounts of individual grains visible when the phosphor of the color is divided into its individual components. Therefore, the white phosphor is a single component, as proposed in USA, Patent application 20070044679 A1, Petrik Viktor I. "White-fluorescent anti-stokes compositions and methods" 01.03.2007; and Petrik V.I., "White-fluorescent anti-stokes composition and methods, WO 2008/004015 A2, 10.01.2008, has significant advantages.

Grain size distribution

On the one hand, a good coating on the surface of the phosphor particles should be small as possible. On the other hand, due to the scattering loss, very small, poorly crystallized phosphor particles have a low intensity glow. In this regard, one must find a compromise between particle size and brightness. The average grain size of the ASL is ~5 μ. The distribution of phosphor grains in size, obtained by the scattering of electron microscopy is shown in Figure 12, which illustrates SEM image Y_2O_2S (Yb,Er) (green) (1 cm = 10 μ).

Example 2 **Quantum points**

Quantum points are micro and nano fragments of conductors or semiconductors (e.g. InGaAs, CdSe or GaInP/InP), the charge carriers of which (electrons or holes) are restricted in space in all three dimensions. At the same time, the dimension of the quantum point influences greatly its quantum effects. The energy spectrum of a quantum point is discrete and the distance between stationary energy levels of the carrier of the charge depends on the dimension of the quantum point as follows: $\hbar^2/2md^2$ (wherein ħ – introduced Planck constant, d – the point's typical dimension, m – the point's effective electron mass). Consequently, the electron and optical properties of quantum points occupy an intermediate position between a volumetrical semiconductor and a discrete molecule.

In analogy of the transition between the atom's energy levels, a photon can be emitted in the transition between the energy levels of a quantum point. At the same time, in contrast to real atoms, the frequency of transitions can be regulated easily by altering the dimensions of the nanocrystallite.

One of the peculiarities of quantum points is that they absorb energy in a broad range of the spectrum, and emit a narrow spectrum of light waves. So, quantum points obtained through the colloid synthesis method on the basis of cadmium chalcogenites, depending on their dimension, fluoresce various spectra in the visible range. For instance, the largest (~2 nm) CdSe crystals luminesce in the blue part of the spectrum, and at 7 nm in the red part of the spectrum. That property allows the obtaining of quantum points with practically any fluorescence wave length from ultraviolet to near-infrared by changing the dimension of the particles and nature of the semiconductor forming the nanocrystal.

Not least important is that quantum points have a very wide (any wave length smaller than the excitation absorption peak) spectrum of absorption, and consequently quantum points of various dimensions can be excited by a single source of light.

Colloidal quantum points are an excellent substitute for traditional organic and inorganic luminophores. They excel them in brightness of fluorescence and photostability, and they also have some unique characteristics. Elaborated have been ways of encapsulation of quantum points in polymere and silico-organic microspheres, allowing an increase in their chemical resistance and photostability.

Thereby, firm body photon emitters, the so-called quantum points, can be applied as sources of light radiation for the protection of credit carda, passports and other documents of strict accountability.

Example 3

The phosphors emitting visible light when excited at ultraviolet, or phosphors preserving energy during excitation in the ultraviolet or visible range and emitting in the visible range for a long time after the cessation of excitation.

The technical task of the invention is the increasing of the degree of protection of physical objects intended for identification and authentication of proprietary information (payment cards, passports, identity certificates, rated account data, other types of personal data) against physical attacks of various levels including forgery, as well as the imitating of the physical presence of given objects.

The problem raised is resolved by that in the method of protecting the physical carrier of information intended for identification and authentication of the subject of the payment system, there are introduced into the matrix of the physical Carrier of information (payment card) or on its surface, substances capable under the influence of electromagnetic radiation of a wavelength of from 0.1 to 10 nm (x-ray range), or of a wavelength of from 10 to 400 nm (ultraviolet range), or a wavelength of from 400 nm to 780 nm (visible range), or of a wavelength of from 780 nm to 59 μm (infrared range) or under the influence of an electric field to luminesce (radiate) in the visible or infrared range, and the determination of the presence of coordinates, dimension, bending angle of the radiating points brought about with the aid of scanners, semiconductor matrices, etc.

At the same time, as a result of the random distribution of radiating substances over the surface or in the composition of the protected object, there is formed a unique pattern peculiar exclusively to the given protected object and is irreproducible at the present level of technology.

Furthermore, the digital graphic representation of the distribution of luminescing points (pattern) is compared with a local or distant data base of patterns of protected objects, formed beforehand with the aim of subsequent identification of the protected objects.

In this case, reliable protection is achieved by that in the mixing of polymer granules with substances radiating in the visible or infrared range, there takes place their chance distribution in the polymer mass or on the surface of the protected object, and on comparison with the data of time, the quantity of radiating points amounts to many thousands, ensuring that the number of their possible combinations of chance distribution can be estimated to be in the quadrillions. From this it follows that the intentional repetition of the distribution of those points with contemporary technological means is impossible.

In a particular case, into the matrix of a credit card or passport or other documents certifying one's identity, there are introduced anti-Stokes compounds, and their excitation is brought about under the influence of electromagnetic radiation of a wavelength of from 780 nm to 59 μm.

In another particular case, into the matrix or onto the surface of the object to be protected are introduced so-called quantum points, and their excitation is brought about under the influence of electromagnetic radiation in the range of from 10 to 400 nm or under the influence of an electric field.

In a particular case, anti-Stokes compounds or quantum points can be introduced into a polymer film. Such a film can be affixed to the surface of construction materials of a payment card or a special information insert of a passport or other documents subject to protection.

CLAIMS

1. Method of protecting physical objects intended for identification and authentication of proprietary information characterized in that on the surface of the product or in its composition there are included special substances, under the influence of electromagnetic radiation or an electric field there can be brought about luminescing in the visible or infrared range, and the control of authenticity is carried out with the aid of comparing the coordinates of radiation points of the substance of the protected object with a local or distant data base of patterns of protected objects.

2. Method according to claim 1, characterized in that the radiating compounds are included into thy matrix of the protected physical object in such a way that fragments of the radiating substance are distributed in the matrix in a random chance way.

3. Method according to claim 1, characterized in that the radiating compounds are put on the surface of the protected physical object in a composition of varnishes or resins or paints, and the fragments of the radiating substance are distributed in a random chance way.

4. Method according to claim 1, characterized in that the radiating compound is included in the composition of a polymer film, and the film is laminated onto the surface of the protected physical object.

5. Method according to claims 2 - 4, characterized in that in the capacity of a radiating substance there are applied anti-Stokes compounds.

6. Method according to claims 2 - 4, characterized in that in the capacity of a radiating substance there are implemented quantum points.

7. Method according to claim 5, characterized in that the excitation of the radiating compound is brought about by electromagnetic radiation of a wavelength of from 780 nm to 59 μm.

8. Method according to claim 6, characterized in that the excitation or the radiating compound is brought about by electromagnetic radiation of a wavelength of from 10 to 400 nm.

9. Method according to claim 1, characterized in that the protected object is placed in a lead-in device in which there are added up the coordinates of radiation points and there is established a digital graphic representation of the distribution of the points – the pattern.

10. Method according to claim 1, characterized in that the pattern of the protected object is compared with a local or distant data base of patterns of protected objects, established beforehand with the aim of subsequent identification of the protected objects.

11. Method according to claim 1, characterized in that a distant or local computer system, on the basis of the coincidence of signs of the pattern of the protected object establishes the identity of the protected object with one of the protected objects the pattern of which is found in the data base, or it reveals an absence of such.

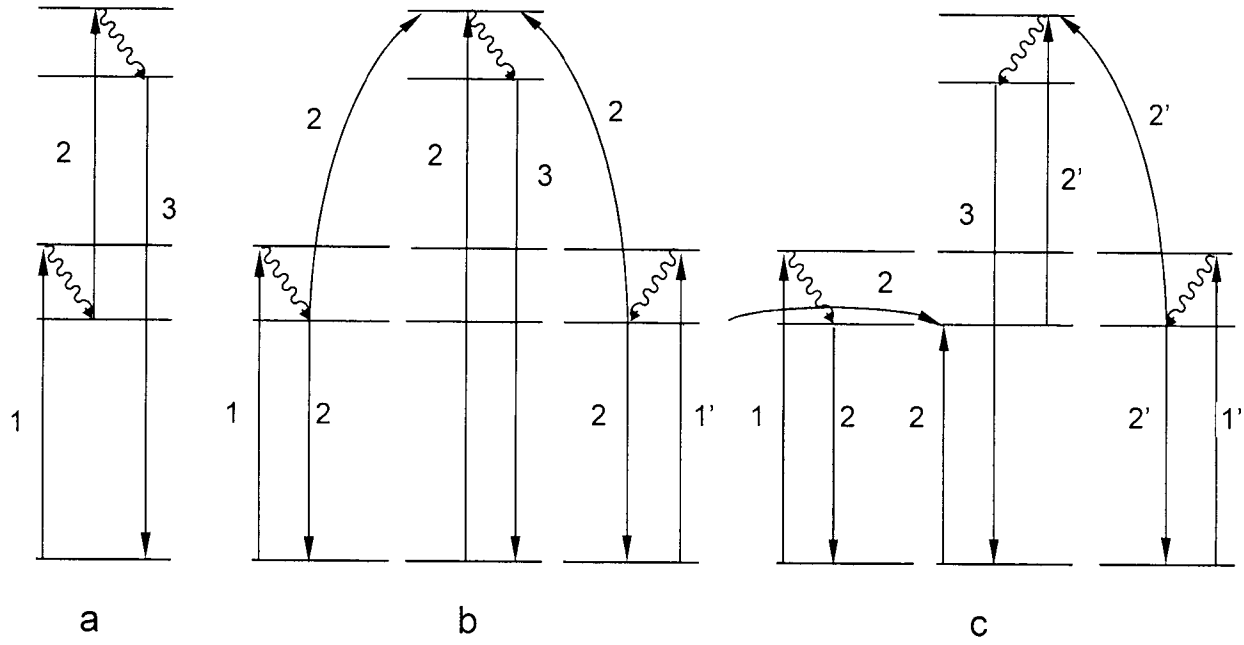


Fig. 1

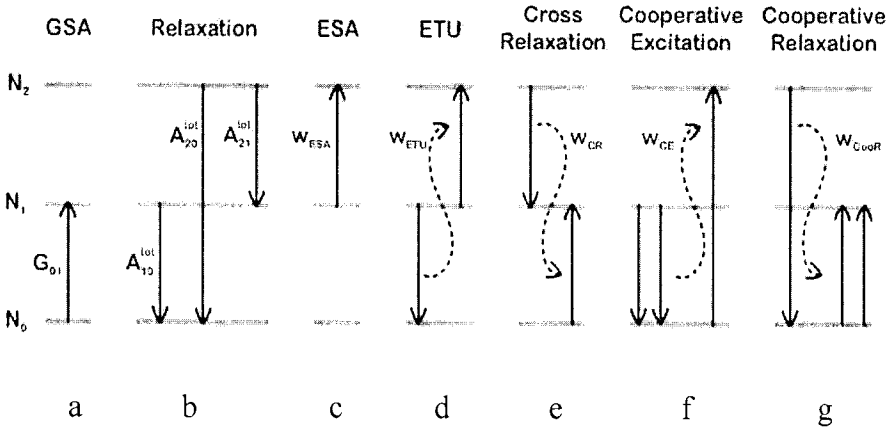


Fig. 2

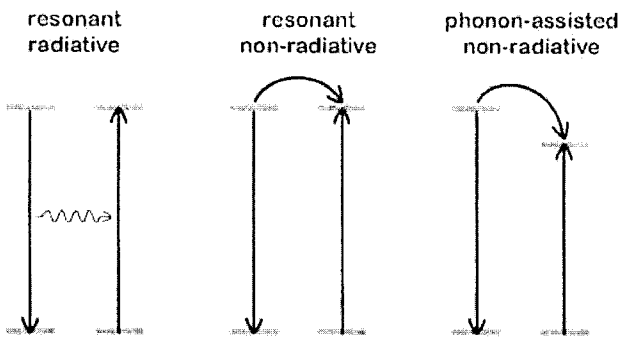
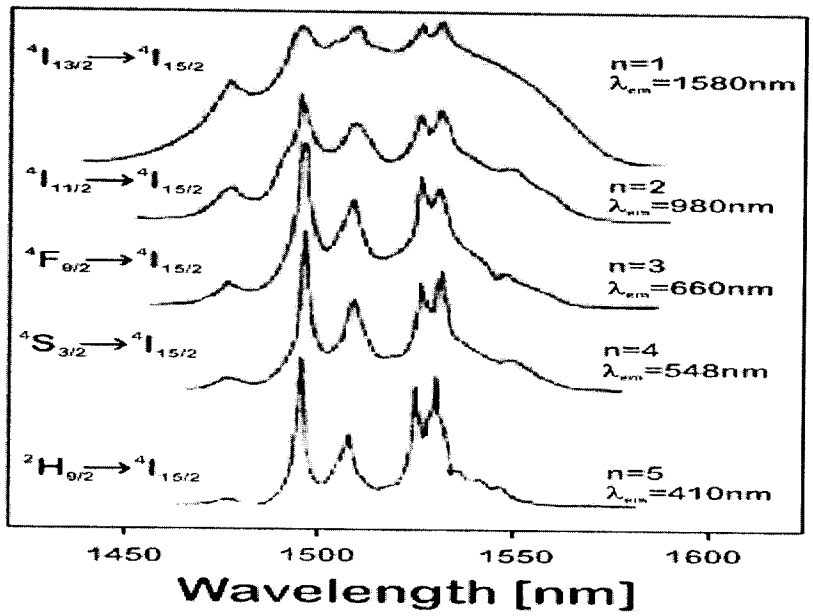


Fig. 3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λ_{em}=1580nm
$^4I_{11/2} \rightarrow {}^4I_{15/2}$
n=2
λ_{em}=980nm
$^4F_{9/2} \rightarrow {}^4I_{15/2}$
n=3
λ_{em}=660nm
$^4S_{3/2} \rightarrow {}^4I_{15/2}$
n=4
λ_{em}=548nm
$^2H_{9/2} \rightarrow {}^4I_{15/2}$
n=5
λ_{em}=410nm
1450
1500
1550
1600
Wavelength [nm]

Fig. 4

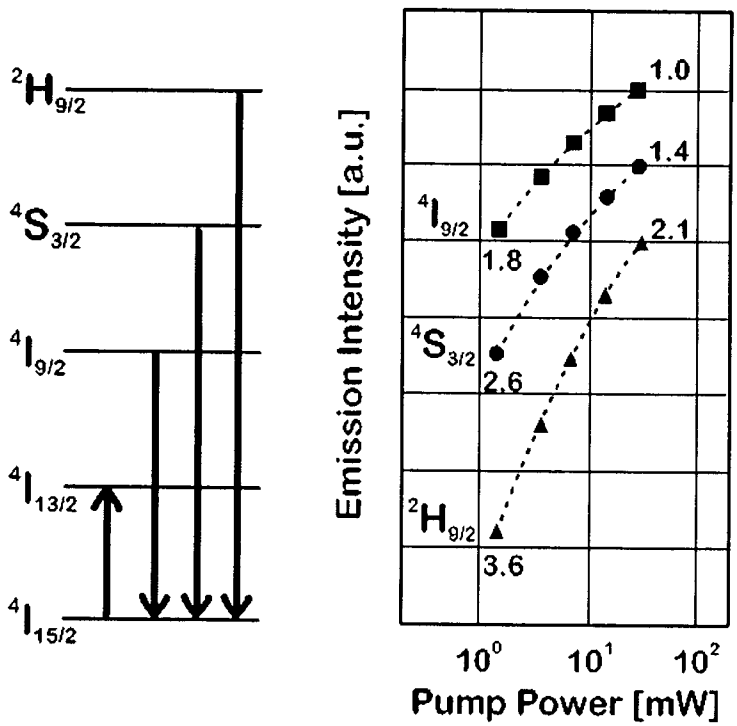
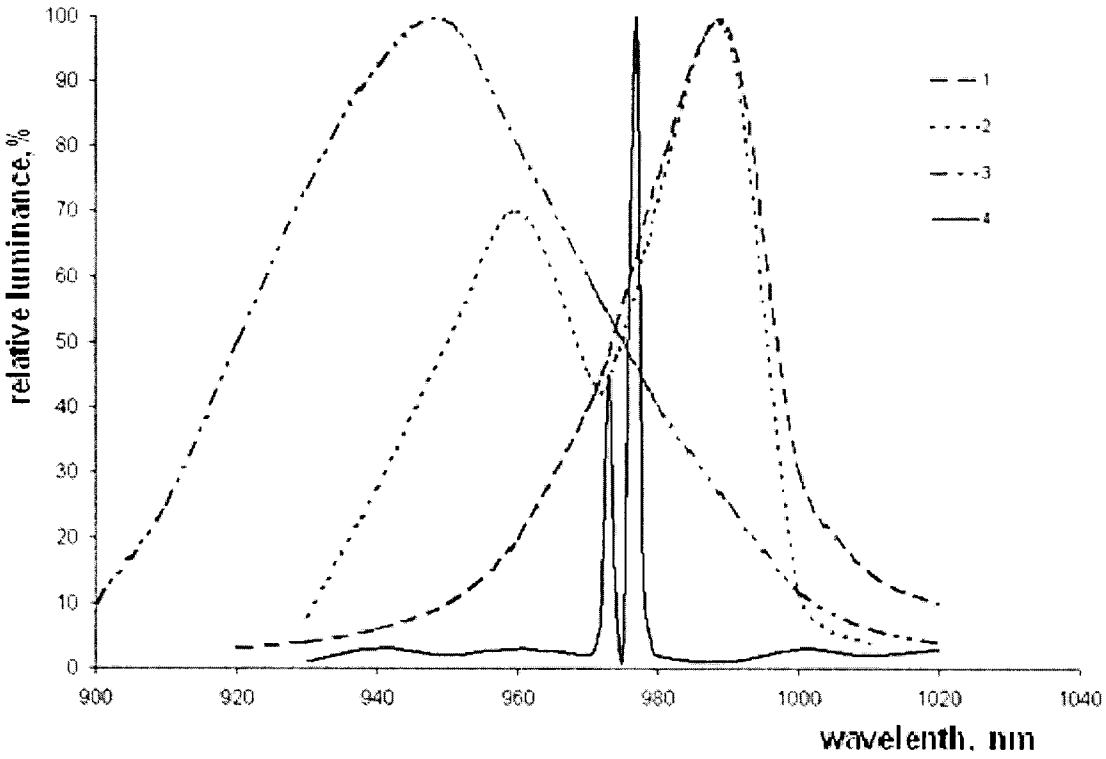

$^2H_{9/2}$
$^4S_{3/2}$
$^4I_{9/2}$
$^4I_{13/2}$
$^4I_{15/2}$
Emission Intensity [a.u.]
1.0
1.4
2.1
1.8
2.6
3.6
10^0
10^1
10^2
Pump Power [mW]

Fig. 5

Influence of up-conversion	Mechanism	Predominant decay route	Absorption of feed power	Power dependence
Small	ESA or ETU	next lower or ground state	small or large	$N_i \sim P^i$ from levels $i=1,...,n$
Large	ETU	next lower state	small or large	$N_i \sim P^{i/n}$ from levels $i=1,...,n$
		ground state	small or large	$N_i \sim P^{1/2}$ from levels i=1,...,n-1 $N_i \sim P^1$ from level i=1
	ESA	next lower state	small large	$N_i \sim P^i$ from levels $i=1,...,n$ $N_i \sim P^{i/n}$ from levels $i=1,...,n$
		ground state	small or large	$N_i \sim P^0$ from levels $i=1,...,n-1$
				$N_i \sim P^1$ from level i=n

Fig. 6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wavelenth, nm
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3
4
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70
60
50
40
30
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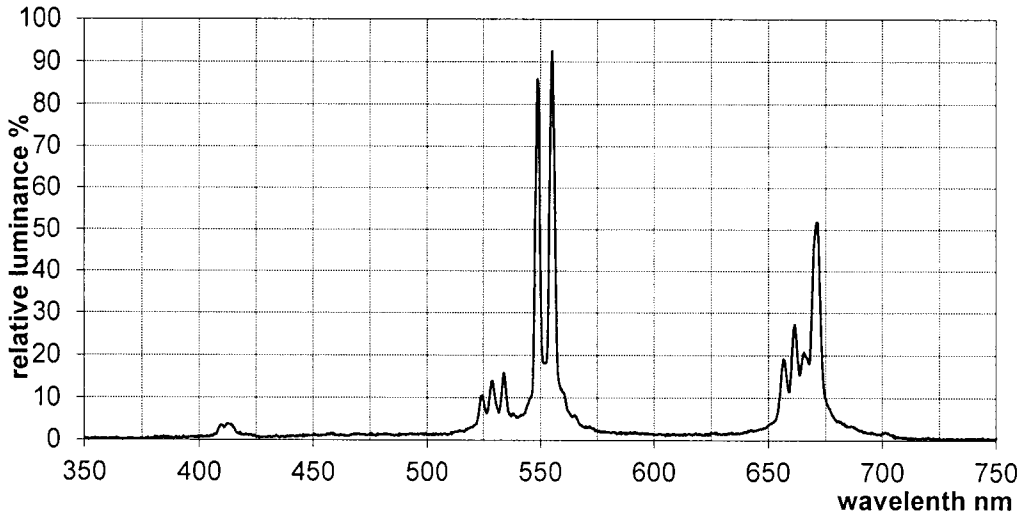
900
920
940
960
980
1000
1020
1040

Fig. 7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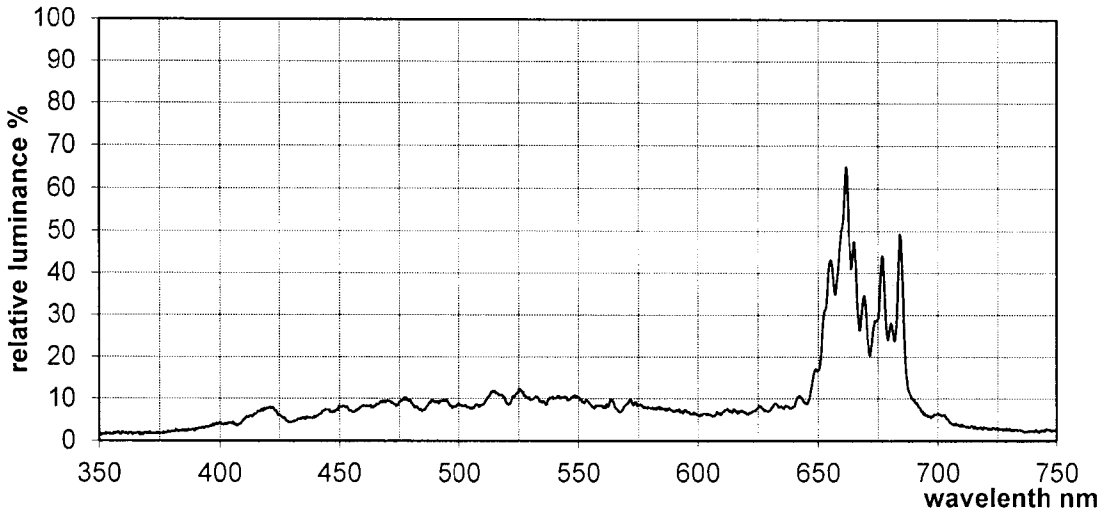
wavelenth nm

Fig. 8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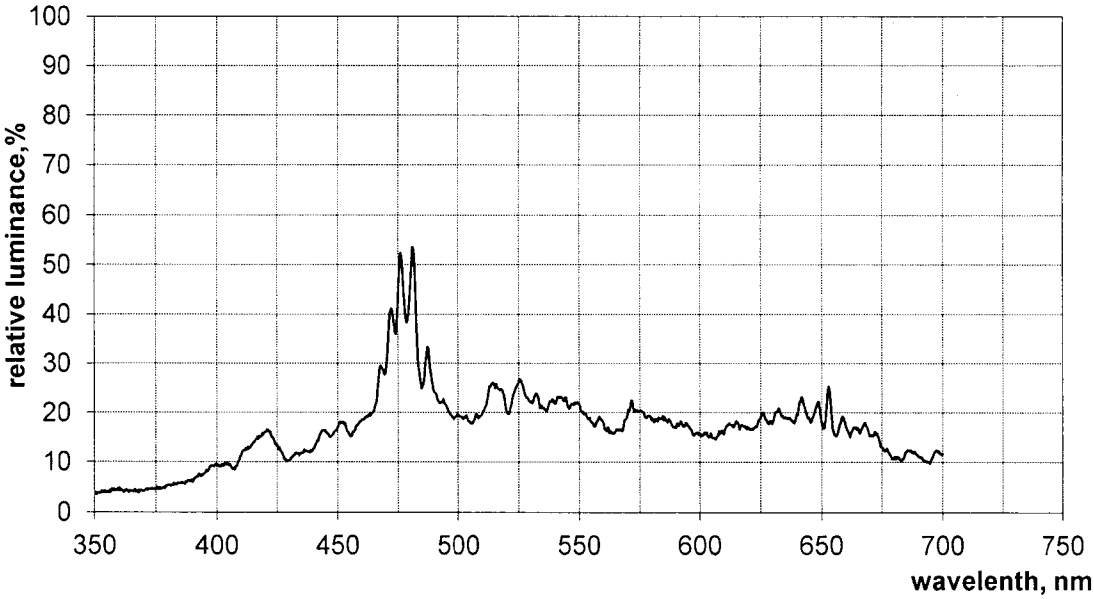
750
wavelenth nm

Fig. 9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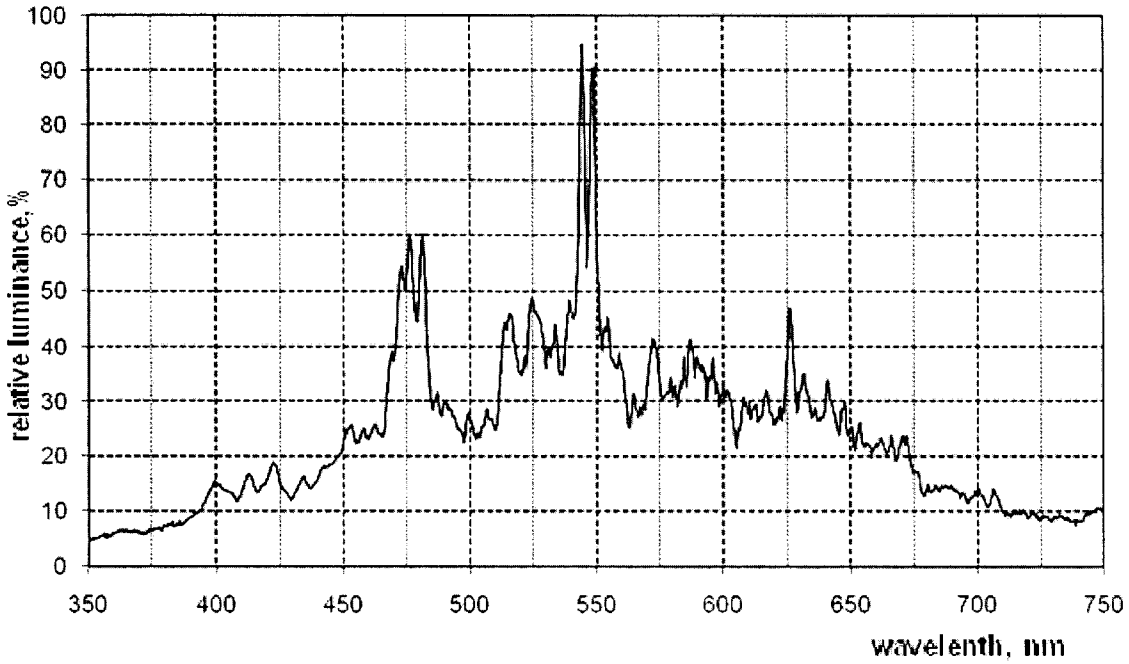
750
wavelenth, nm

Fig. 10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700
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wavelenth, nm

Fig. 11

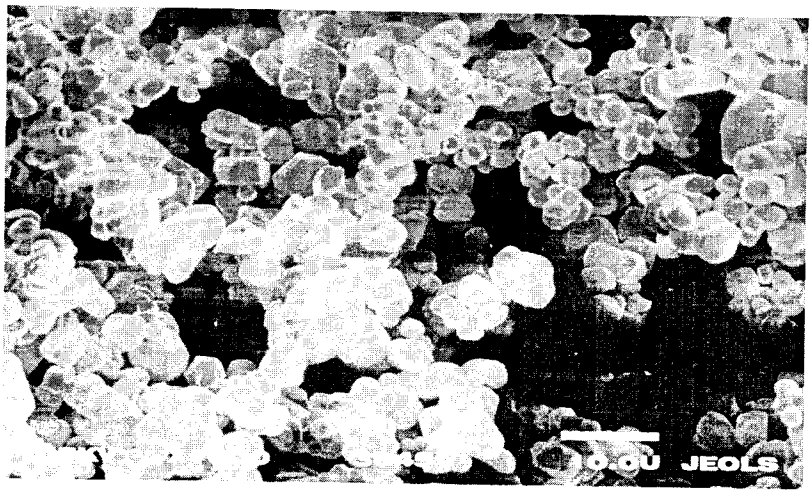
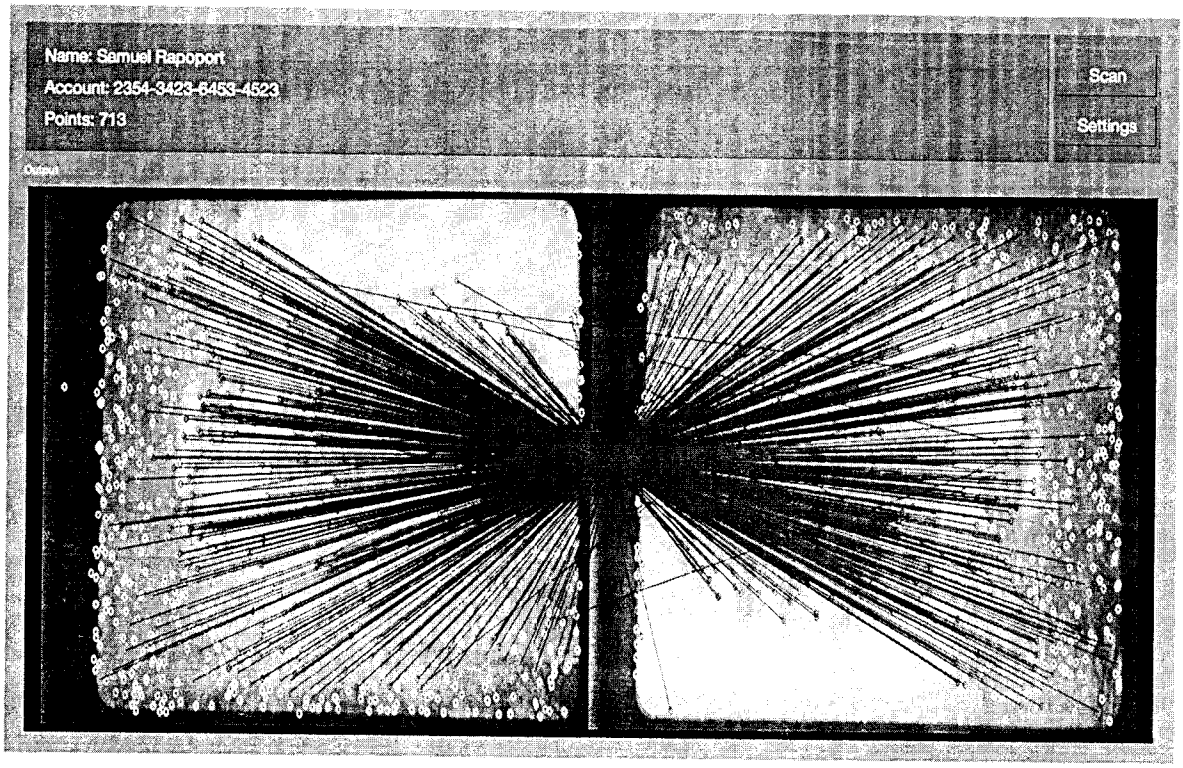

JEOLS

Fig. 12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Account: 2354-3423-8453-4523
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Fig. 13