

Title: METHOD FOR MANUFACTURING PHOTOCONVERTER

This invention relates to a method for manufacturing a photoconverter and, more particularly, to a method which is suitable for manufacturing a photoconverter for
5 absorbing incident light from a radiation source to be excited and emitting light having a longer wavelength than that of the incident light on the basis of an emission peculiar to luminous atom, or on di-quantum or multi-quantum emission basis.

10 A photoconverter of the type referred to is capable of performing the emission peculiar to the luminous atom or the multi-quantum emission with the incident light from the radiation source for its photoconversion at a high energy efficiency, as provided, for example, on the
15 periphery of a tube surrounding the radiation source, that is, on the inner or outer peripheral surface of a lamp tube in the case of an elongated or spherical lamp, and thus should find its usefulness when applied to such lamps and the like.

20 An example of generally utilized photoconverters is fluorescent substance used in fluorescent lamps. In such fluorescent lamps using the fluorescent substance as the photoconverter, their luminous efficiency reaches about 80lm/W, which is
25 relatively high among existing lamps. From the viewpoint of energy conversion efficiency, on the

other hand, there has been a problem that the fluorescent lamp can utilize only about a quarter of the input energy while the fluorescent substance itself shows an efficiency of utilization of only less than one half of the input
5 excitation light, and thus that theoretically no sufficient luminous efficiency has been gained.

For solving the above problem, the present inventor Makoto Toho has suggested as disclosed in U.S. Patent No. 4,710,386 (or corresponding U.K. Patent No. 2,167,428 or
10 German Patent Offenlegungsschrift P 35 37 881.6) a photoconverter in which the luminous atoms having the atomistic property are fixed as dispersed among intermediate substances permeable to light so as to be substantially individually isolated from one another so
15 that, upon incident of light, the photoconverter is excited to cause each exciting photon to emit two or more photons for realizing the multi-quantum emission. In manufacturing this photoconverter, one of such working techniques as Langmuir's film forming method, superfine
20 particle forming method, super alloy forming method, microfilm forming method and so on may be employed.

In manufacturing the photoconverter with such working technique as in the above, however, there has been a problem in respect of the production efficiency and
25 economics as well, and it has been desirable that substantially the same level of the production efficiency and economy as the fluorescent substance in the ordinary fluorescent lamp which emits light with luminous

ultraviolet ray due to a low pressure mercury discharge irradiated and converted into the visible light will be realized. That is, in the manufacturing method of the ordinary fluorescent lamps, it has been only necessary
5 to apply a solution of the fluorescent substance onto the inner surface of a glass tube, to dry and fire the applied solution, and thereafter to tightly seal mercury and rare gases in the glass tube, so as to be extremely highly efficient in production, and it has been demanded
10 that a method is provided for allowing the photoconverter excellent in the easy usage to the same level as the fluorescent substance in such fluorescent lamps to be manufactured.

A primary aim of the present invention is,
15 therefore, to provide a method for manufacturing a photoconverter in which the luminous atoms are fixed in atomic state as individually isolated within a solid member for an emission peculiar to the luminous atoms, or for di-quantum or multi-quantum emission, and
20 excellent in the easy usage to the same extent as the fluorescent substance used in the fluorescent lamps, through similar steps to those in the method for manufacturing the fluorescent substance in the fluorescent lamps and with a highly efficient industrial
25 producibility.

Accordingly, the present invention provides a method for manufacturing a photoconverter for at least an emission peculiar to luminous atoms, the photoconverter having a luminous substance layer in which luminous

substances are fixed to be substantially individually isolated within a matrix substance permeable to visible light, the luminous substances being for absorption of incident light from a radiation source to be thereby
5 excited to convert it into a light of a longer wavelength than that of the incident light, wherein the method comprises the steps of forming a sol by obtaining a mixture solution of a matrix compound capable of forming a sol-gel film containing said matrix substance
10 component with an acid chloride compound containing luminous atoms, forming said sol into a coating over a substrate comprising a glass tube, and thereafter calcining said coating to reduce and sinter it, the luminous atoms being fixed in individual isolation in
15 microfine pores formed in the coating by the calcination.

Preferably, the sol forming step employs as said matrix substance at least one selected from the group consisting of SiO_2 and Al_2O_3 .

20 The invention will now be described in detail, by way of example, with reference to the drawings, in which:-

FIGURE 1 is a diagram showing the steps in an embodiment of the method for manufacturing a
25 photoconverter according to the present invention;

FIG. 2 is a diagram showing schematically the state of sol attained in a sol forming step of FIG. 1;

FIG. 3 is a schematic, fragmentary sectioned view of the film formed at the film forming step after a primary
30 calcining step of FIG. 1;

FIG. 4 is a schematic, fragmentary sectioned view of the photoconverter obtained after a secondary calcining step in the manufacturing method of FIG. 1;

5 FIG. 5 is a diagram for explaining the energy level of Fe atom employed in the method of FIG. 1;

FIG. 6 is an explanatory diagram for excitation characteristics of the photoconverter obtained with Fe atom employed in the method of FIG. 1;

10 FIG. 7 is an explanatory diagram for luminous characteristics of the photoconverter obtained with Fe atom employed in the method of FIG. 1;

FIG. 8a is an explanatory diagram for absorption spectrum of Fe atom employed in the method of FIG. 1;

15 FIG. 8b is a diagram showing a main peak absorption spectrum for luminous atom of the photoconverter with Fe atom employed, as obtained through the steps of FIG. 1;

FIG. 9 is an explanatory diagram for transition emission of Na atom employed in the method of FIG. 1;

20 FIG. 10 is an explanatory diagram for the transition emission of Na atom employed in the method of FIG. 1 as fixed in atomic state;

FIG. 11 is an explanatory diagram for the luminous characteristics of the photoconverter obtained with Na atom employed in the method of FIG. 1;

25 FIG. 12 is a diagram showing the steps in another embodiment of the method for manufacturing the photoconverter according to the present invention;

FIG. 13 is a schematic, fragmentary sectioned view of

the film formed at the primary calcining step in the method of FIG. 12;

FIG. 14 is a schematic, fragmentary sectioned view of the photoconverter obtained after the secondary calcining
5 step in the method of FIG. 12;

FIG. 15 is an explanatory diagram for the energy level of Sr atom employed in the method of FIG. 12;

FIG. 16 is an explanatory diagram for the energy level of Mn atom employed in the method of FIG. 12;

10 FIG. 17 is an explanatory diagram for the luminous characteristics of Sr atom employed in the method of FIG. 12 and fixed in the atomic state;

FIG. 18 is an explanatory diagram for the luminous characteristics of Mn atom employed in the method of FIG.
15 12 and fixed in the atomic state;

FIG. 19 is an explanatory diagram for the luminous characteristics of Fe atom employed in the method of FIG. 12 and fixed in the atomic state;

FIG. 20 is an explanatory diagram for the luminous
20 characteristics of the photoconverter obtained through the method of FIG. 12;

FIG. 21 is an explanatory diagram for the energy level of Li atom employed in the method of FIG. 12;

FIG. 22 is an explanatory diagram for the luminous
25 characteristics of Li atom employed in the method of FIG. 12 and fixed in the atomic state;

FIG. 23 is an explanatory diagram for the luminous characteristics of In atom employed in the method of FIG.

12;

FIG. 24 is an explanatory diagram for the luminous characteristics of Na atom employed in the method of FIG. 12 and fixed in the atomic state;

5 FIG. 25 is an explanatory diagram for the luminous characteristics of In atom employed in the method of FIG. 12 and fixed in the atomic state;

FIG. 26 is a schematic, fragmentary sectioned view of a photoconverter in another embodiment according to
10 the method of FIG. 12;

FIGS. 27 and 29 are diagrams for showing schematically respective models in which the photoconverter is produced, for explaining sintering temperature adjustment in the method according to the
15 present invention;

FIGS. 30 to 32 are diagrams showing energy shift models of the fixed luminous atom, corresponding to FIGS. 27 to 29;

FIGS. 30 to 32 are diagrams showing energy shift
20 models of the fixed luminous atom, corresponding to FIGS. 27 to 29;

FIG. 33 is a diagram for explaining the adjustment and setting of the sintering temperature in the method according to the present invention; and

25 FIG. 34 is a diagram for explaining the radiative transition of Na atom in the excitation of ultraviolet light due to general mercury discharge.

Reference will first be made to Fig. 1 of the drawing which shows schematically a method for manufacturing a photoconverter according to the present invention in which a mixture solution is obtained first
5 by mixing a metallic atom salt of desired luminous atom such as ferric nitrate $\text{Fe}(\text{NO}_3)_3$ containing Fe atom with water H_2O and an alcohol such as ethanol $\text{C}_2\text{H}_5\text{OH}$ to obtain a density ratio of Fe atoms to SiO_2 molecules of about 1:1,000 so that they will be at 1:1 in volume
10 ratio or at a ratio adjacent thereto. Next, an equal amount or more of a matrix compound which can be a source material of a matrix substance, preferably, tetraethoxysilane (as a source material of amorphous silica SiO_2 which will be the matrix substance of the
15 photoconverter), is mixed with the above mixture solution, with several drops of such a source material of salt of the luminous atom as undiluted nitric acid added.

The eventual mixture solution is kept at normal
20 temperatures, i.e., about 20°C or slightly heated, for example, in a range of about 50 to 60°C , and is agitated for a relatively long time, for example, several hours to a whole day and night. Through this agitation, the solution is made to be a sol, that is, such a silica sol
25 as shown preferably in FIG. 2, in which silica colloid x is present dispersed in the solution.

Next, this mixture solution made into a sol is applied to a surface of a substrate, such as an inner surface of a lamp glass tube, so as to be a coating thereon, and then this substrate with the coating is heated in the atmosphere at a higher temperature, for example, about 500°C for 1 to 2 hours, to execute a primary calcination, during which the coating is decomposed into a matrix substance 12 consisting of amorphous silica SiO having a number of microfine pores and $\text{Fe}(\text{NO}_3)_3$ retained in the pores, the latter of which is eventually caused to produce FeO with NO_x (NO_2) scattered, as shown in FIG. 3, in which a numeral 11 denotes the substrate.

Next, the substrate 11 on which the matrix substance 12 is fixed is subjected to a secondary calcination in an atmosphere of carbon monoxide or hydrogen or the like atmosphere, at such a high temperature as 100 to 1,000°C for a relatively short period, so as to be reductively sintered, and a photoconverter is produced as a sintered film on the substrate 11. In this event, it will be appreciated by any one skilled in the art that the calcining temperature history is subjected to a preliminarily set administration or a feedback administration for rendering the film to be of a desired size in the pores in which the luminous atoms are contained.

In the photoconverter produced as reductively sintered, only Fe in FeO is reduced, Fe atoms are retained in the microfine pores of the matrix substance 12 as made

individually independent, and such a fixed film 13 as shown in FIG. 4 is caused to be formed on the substrate 11. When ultraviolet ray emitted by a mercury discharge is made incident on this photoconverter in the form of this fixed film 13, the luminous atoms absorb this ultraviolet ray to be thereby excited to cause an emission transition to occur, and the film can be utilized as a fluorescent substance which emits a desired visible light.

In the concrete, the ratio of the number of Fe atoms with respect to the number of Si atoms was selected to be 1:1,000 as the luminous intensity in obtaining the film in the embodiment of FIG. 1, in which event it has been found that the photoconverter obtained has shown the property of atomic state substantially corresponding to the energy level of Fe atom as shown in FIG. 5, that is, such excitation property of the relative excitation strength high with respect to the wavelength of around 240nm as shown in FIG. 6, and such luminous property of the relative luminous strength high with respect to the wavelength of around 450nm. In this case, three absorption spectra appearing in the excitation property shown in FIG. 6 are characteristic to Fe atom, while the absorption spectrum of Fe atom itself should appear around the wavelength of 250nm and 270nm as shown in FIG. 8a. In the photoconverter according to the present invention, on the other hand, a slight deviation of 10 to 20nm is caused to occur in the energy level due to a weak van der Waals coupling of Fe atom to adjacent silica substance, so as to

cause the absorption spectra to appear around 240 to 250nm of the wavelength as shown in FIG. 8b and thus to attain the so-called atomic state which is closer to the atom rather than Fe atom itself. However, as will be appreciated, the photoconverter of the present invention allows a blue color emission of the wavelength of 400 to 450nm peculiar to Fe atoms with the excitation of the ultraviolet ray to be highly efficiently obtained as in FIG. 7 due to the main luminous ultraviolet ray of 254nm by means of low pressure mercury discharge, so that the photoconverter will be extremely useful as the fluorescent substance for use in the fluorescent lamp.

In the embodiment of FIG. 1, it is possible to execute a film form control in respect of such finishing conditions of the film 13 as the density, film thickness, extent of the atomic state and so on, by means of an addition of any additives for controlling the porous distribution (size or diameter of pores and degree of dispersion), setting of the ratio of the number of the luminous atoms versus the number of the matrix atoms, setting of the concentration of the solution or the number of application of the solution for forming the coating and eventually the film, temperature regulation, controlling of sintering temperature history and so on, as occasion demands. On the other hand, it is also possible to freely vary the fluorescent color by altering the luminous atom itself, and an emission peculiar to the luminous atoms or a di-quantum emission can be realized highly efficiently

by employing different ones of the luminous atoms, as has been also disclosed in the foregoing U.S. Patent No. 4,718,381.

When the thin film is formed in accordance with the method described with reference to the embodiment of FIG. 1 with the sol formed by a desired metallic atom salt and the luminous atom of, for example, Na atom, this luminous atom is caused to execute the emission transition as in FIG. 9, and such emission transition as in FIG. 10 which presenting a slight energy shift and broadening is made to be shown by fixing Na atom in the atomic state. When an ultraviolet ray of 254nm having an energy of about 4.9V is made incident on this film, the light is excited highly efficiently to a higher excitation level of the same energy, for example, to a P series level, the thus excited energy is subjected to a transition therefrom to an adjacent S or D series due to level overlapping of Na atom with an adjacent series, a blue series visible radiation transition of a first step therefrom to $3P_{1/2}$ and $3P_{2/3}$ levels and sequentially a yellow series resonance radiation transition of a second step from the same level to the ground level are highly efficiently caused to occur, and such visible light emission peculiar to the luminous atoms or di-quantum visible light emission as shown in FIG. 11 can be efficiently performed. For the luminous atoms, it is of course possible to selectively employ any other atoms than the foregoing Fe and Na atoms.

Referring next to FIG. 12 showing another embodiment

of the method according to the present invention, there is provided a method for manufacturing a photoconverter in which three different luminous atoms contributive to respective colored emission of red R, green G and blue B are fixed in the atomic state.

More specifically, in the present embodiment, the mixture solution of the metallic atom salt is prepared by mixing, in addition to $\text{Fe}(\text{NO}_3)_3$, $\text{Sr}(\text{NO}_3)_3$ and $\text{Mn}(\text{NO}_3)_3$ at such optimum radio as 1:2:1 in the atomic density ratio.

This mixing step is followed by the same steps as those in the embodiment of FIG. 1. In the present instance, the three different metallic atoms oxidized after the primary calcination are made to be in mutually separated state as shown in FIG. 13 and, when the film 13 is attained on the substrate 11 through the secondary calcination for the reductive sintering, the three different luminous atoms are separately fixed in the atomic state as shown in FIG. 14. These three different atoms of Sr, Mn and Fe which are the respective luminous atoms for R, G and B are of such energy levels as shown in FIGS. 15 and 16 as well as FIG. 5 referred to with reference to the embodiment of FIG. 1, so that, due to their fixation in the atomic state, their excitation by the ultraviolet ray of 254nm by means of the mercury discharge will cause the three different luminous atoms to execute respectively a fluorescent emission slightly vigorous in red, green or blue color as shown in FIG. 17, 18 or 19 while accompanying a slight energy shift. When these Sr, Mn and

5 Fe atoms are mixed in a ratio of about 1:2:1 in the number of atoms, it is possible to obtain a photoconverter of a whitish emission as a whole and excellent in the color rendering with three primary colors R, G and B contained respectively at a proper amount as shown in FIG. 20.

10 Since, in this case, Sr and Mn atoms show the peculiar emission of the luminous atoms or the di-quantum or multi-quantum emission of a high efficiency, the photoconverter as a whole of the present embodiment provides an extremely highly efficient emission. Further, when Li atom showing such energy level as shown in FIG. 21 is employed in place of Sr atom, the Li atom as fixed in the atomic state is effective to show such fluorescent emission as shown in FIG. 22, and substantially the same effect as in the above can be attained. Further, it is also possible to substitute Na atom which provides an emission of such energy level as in FIG. 9 and such atomic state as in FIG. 24 or In atom which provides an emission of such energy level as in FIG. 23 and such atomic state as in FIG. 25 for Sr atom or Fe atom, with the same level of effect allowed to be expected. Any other luminous atoms than those described may be employed as desired.

25 It is also possible to obtain the photoconverter by combining only two different atoms which are vigorous in the emission of more than two among R, G and B, the emission of which photoconverter still maintaining effectively respective components of the three principal colors R, G and B. The respective atoms may be employed

in such combinations as Sr and Mn atoms, Sr and Li atoms or In and Mn atoms.

It has been found that the foregoing luminous atoms provide such strong excitation and emission properties as shown in a following table, as being the atoms or in the atomic state.

TABLE

Atom	Excitation	+	Non-transition emission	+	Transition emission
Sr	5s	+	7p		⁺ BG 5p ⁺ R 5s
Mn	3d	+	4p		⁺ B 4p ⁺ R 3d
Fe	4s	+	np (n $\geq$ 4)		⁺ B $\rightarrow$ 4s
Li	2s	+	np (n $\geq$ 4.5)		⁺ B 2p ⁺ R 2s
Na	3s	+	np (n $\geq$ 7)		⁺ B 3p ⁺ YO* 3s
In	5p	+	8s or 6d		⁺ R 6s ⁺ B 5p

(Remark*: YO = Yellowish Orange)

Further, it is also possible to form the photoconverter containing the more than two different luminous atoms without employing such mixing step of the more than two different metallic atom salts at the initial step of the manufacturing method shown in FIG. 12, but rather by forming sequentially each of three films with each of the metallic atom salts in the same manner as in the embodiment of FIG. 1 so as to stack respective films 13A, 13B, 13C... respectively in which the different luminous atoms are separately contained as fixed to the atomic state as shown in FIG. 26. In carrying out the

excitation by means of the ultraviolet ray of 254nm with the mercury discharge, further, it is made possible to attain a highly efficient peculiar visible light emission of the luminous atoms or di-quantum or multi-quantum visible light emission by employing, as the luminous atoms, Al, Co, Sn, Ta, V, W, Hf, Mg, Ni, Re, Si, Y and so on, in addition to the luminous atoms of Na, Li, Sr, Mn, In and so on. In respect of the excitation, the use of the ultraviolet ray due to the mercury discharge has been described in the above, but it is also possible to employ other visible light or ultraviolet ray of other wavelength or an excitation light source, while it is also possible to utilize an atom of a luminous property of invisibility in accordance with the object and use of the fluorescent emission. For example, a peculiar emission of luminous atoms or multi-quantum near ultraviolet emission may also be carried out with an ultraviolet ray irradiation from a xenon arc lamp with respect to the photoconverter in which Zn atom is fixed.

According to another feature of the present invention, there can be provided an extremely useful method for manufacturing the photoconverter which can improve the probability of transition and thus can perform the peculiar emission of the luminous atoms or the di-quantum emission at a high efficiency. In an embodiment of this feature, pores 15 formed in the matrix substance 12 are made to have a diameter d which is so set as to accommodate the luminous atom 14 for generating the most desirable

transition, as shown in FIG. 27, at the step of secondary calcination for the reductive sintering in the manufacturing method of FIG. 1 or 12. In the case of the present embodiment, a proper selection of the temperature for the secondary calcination can be contributive to the formation of the photoconverter capable of achieving the highly efficient di-quantum emission. Here, the secondary calcining temperature which is too low will result in such excessively large diameter of the pore 15 as seen in FIG. 28, while the temperature too high will result in such too small diameter as in FIG. 29. In an event where the luminous atom 14 produced in the matrix substance 12 is accommodated in such pores 15 having a proper diameter, there is caused an extremely weak van der Waals coupling, that is, an extremely weak intermolecular coupling to occur between the luminous atom 14 and adjacent atoms or moleculars, so as to be fixed with the atomic state maintained, within the matrix substance 12. In other words, it will be appreciated that the diameter d of the pores 15 is so set as to cause the extremely weak van der Waals coupling of the luminous atoms 14 with the adjacent atoms or moleculars.

In such state where the luminous atoms are fixed in the atomic state in which these atoms are in the extremely weak van der Waals coupling with the adjacent atoms or moleculars, mutually adjacent and equal energy excitation levels are superposed on the energy level of the luminous atoms, so that an optimum energy shift or broadening can

be attained. With this energy level superposition, it is made possible to elevate the probability of transition, and the reasons therefor shall be described in detail.

It has been made known that, in the excitation energy level of the luminous atom, the radiation or absorption generally takes place in accordance with the "Pauli's exclusion principle" and only between the levels based on this principle. Strictly speaking, it has been found that the transition occurs only between the units of series which are different only by "1" in the number of main quanta (n), the units of series thus corresponding to $n=1, 2, 3, \dots$ in the energy level while the series being denoted by such alphabetic characters as S, P, D, F, ..., and no emission transition takes place between such series as S and D or S and F. Referring to FIGS. 9 and 10 showing the emission transition of Na atom and atomic state Na atom, for example, it is seen that the transition occurs without jumping width as drawn by each line in the drawings upon the optical excitation by the ultraviolet ray of 254nm obtained by means of the mercury discharge in the case of the photoconverter in which Na atom is fixed in the atomic state. Here, the desired emission transition of the peculiar emission of the luminous atoms or di-quantum emission takes place as shown by straight line arrows in FIG. 34, while such non-emission transition of $nP + nS$ or $nP + nD$ as shown by wavy line arrows in the drawings can hardly occur in such event as a rarefied gas where atoms substantially have no chance of mutual

collision. In a state where the luminous atoms are completely independent of one another and fixed in the atom as it is, the probability of the non-emission transition is made less as in the case of the rarefied gas, while the emission transition occurring from nP to nS or to nD as shown by solid line arrows is generally low in the probability, and the transitions from nP involve one to other levels shown by broken lines in FIG. 34 and the one from nP to nS or to nD should not be always excellent in the transition efficiency.

In the present embodiment, on the other hand, the superposition on each other of the mutually adjacent and equally excited energy levels in the photoconverter having the luminous atoms fixed in the atomic state within the pores 15 of such proper diameter as shown in FIG. 27 causes the levels to have a certain width, so that a level AL which is to achieve the absorption and excitation as well as an equal level EL in an adjacent series to execute a proper energy shift and broadening with respect to the ground level GL , the non-emission transition is caused by such superposition to occur at a high probability so as to allow as a whole the peculiar emission of the luminous atoms or the di-quantum emission transition to be extremely easily performed, and the emission efficiency can be remarkably elevated. In this case, the secondary calcining temperature excessively low and the pore diameter excessively large as in FIG. 28 result in such excessively small energy shift and broadening as shown in

FIG. 31, while an excessively high secondary calcining temperature and an excessively small pore diameter as in FIG. 29 will result in such excessively large energy shift and broadening as shown in FIG. 32, and any desired
5 excitation and emission transition process can be hardly attained.

It is thus required to take the temperature setting and regulation sufficiently into consideration in the step of the secondary calcination. In this connection, if
10 required, a proper secondary calcining temperature can be determined in such that, as shown in FIG. 33, a material to be tested which has been primarily calcined at a previous step is subjected to the secondary calcination within a sintering furnace 20 to obtain a testing
15 photoconverter 13, during which secondary calcination the relationship between the sintering temperature and the fluorometric intensity are measured with a variable length laser 21 and a spectrometer 22 employed, and the proper temperature for the secondary calcination is determined in
20 view of the thus measured sintering temperature upon obtention of excellent one of the testing photoconverter 13.

It should be appreciated on the other hand that the appropriate energy level shift and broadening are
25 particularly effective in the event where, for example, the inherent excitation level of pure atom is not in conformity to the excited energy of the fixed atoms, that is, the former level can be made conforming to the excited

energy, so that the excitation can be made to occur even in the atoms in the atomic state, and that, since the absorption and excitation efficiency can be elevated by setting the excitation energy level substantially at the same energy level as the excitation emission energy by means of the foregoing energy shift and broadening, a selection range of the luminous atom employed in the photoconverter or of an excitation light source can be sufficiently broadened.

In the present embodiment, other arrangements are the same as those in the foregoing embodiment of FIG. 1 or 12, and substantially the same function can be attained.

CLAIMS

1. A method for manufacturing a photoconverter for at least an emission peculiar to luminous atoms, the photoconverter having a luminous substance layer in which luminous substances are fixed to be substantially individually isolated within a matrix substance permeable to visible light, the luminous substances being for absorption of incident light from a radiation source to be thereby excited to convert it into a light of a longer wavelength than that of the incident light, wherein the method comprises the steps of forming a sol by obtaining a mixture solution of a matrix compound capable of forming a sol-gel film containing said matrix substance component with an acid chloride compound containing luminous atoms, forming said sol into a coating over a substrate comprising a glass tube, and thereafter calcining said coating to reduce and sinter it, the luminous atoms being fixed in individual isolation in microfine pores formed in the coating by the calcination.

2. The method according to claim 1, wherein said sol forming step employs as said matrix substance at least one selected from the group consisting of SiO_2 and Al_2O_3 .

3. The method according to claim 1 or claim 2, wherein said sol forming step employs for said luminous atoms at least an element selected from the group consisting of Fe, Mn, Sr, Na, Li, In and Ni.



4. The method according to claim 3, wherein said luminous atoms are of at least an element selected from the group consisting of Al, Co, Sn, Ta, V, W, Hf, Mg, Re, Si and Y.

5. The method according to any preceding claim, wherein said sol forming step employs, as said matrix compound, a silicon compound containing amorphous silica as said matrix substance and, as said acid chloride compound, a metallic atom salt.

6. The method according to any preceding claim, wherein said sol forming step employs for said luminous atoms at least two different luminous atoms in a mixture, each of said different atoms showing a strong emission of at least one of red, green and blue colours.

7. The method according to claim 6, wherein, as said luminous atoms, at least an element selected from the group consisting of Fe and Mn and at least an element selected from the group consisting of Sr and Li are employed.

8. The method according to claim 2, wherein, for said luminous atoms, Fe is employed.

9. The method according to claim 2, wherein, for said luminous atoms, Mn is employed.

10. The method according to any preceding claim, wherein said calcining step is performed at a temperature which causes an energy shift and broadening of the excitation level of said luminous atoms to such an extent that the luminous atoms maintain their atomic state during said reduction and sintering.



11. The method according to claim 10, wherein said calcining temperature is so set that said luminous substance layer will have pores of a diameter effective to accommodate therein said luminous atoms upon said sintering and to cause an energy shift and broadening to occur.

12. A method for manufacturing a photoconverter substantially as described herein with reference to the drawings.

13. A photoconverter made by the method claimed in any one of the preceding claims.

