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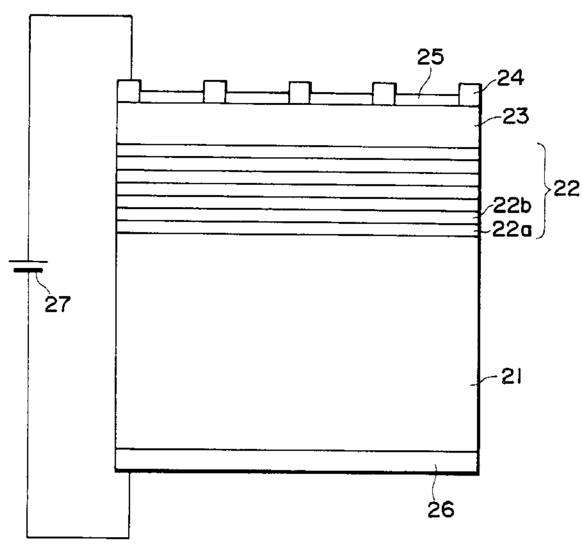
(54) **Photoelectron emitting structure, and electron tube and photodetecting device using the photoelectron emitting structure.**

(57) The conventional photoemitting surfaces cannot efficiently absorb incident long-wavelength photons. In the photoemitting surface according to this invention, the absorption of incident photons, and the generation of electron-hole pairs take place between sub-bands of conduction bands or between sub-bands and the bottoms of the conduction bands, and the generated photoelectrons are further accelerated by a internal electric field. Accordingly the photoemitting surface can be sensitive to incident long-wavelength photons. In the electron tubes using the photoemitting surface according to this invention, and the photodetecting devices using these electron tubes, photometry, imaging, etc. can be effectively performed at low illuminance.

Fig. 4



EP 0 558 308 A1

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates to a photoelectron emitting structure which emits photoelectrons by the incidence of photons, and an electron tube and a photodetecting device using the photoelectron emitting structure.

Related Background Art

The art using semiconductor multi-layer films as a photoabsorbing layer for the end of providing a highly efficient photoelectron emitting structure are disclosed in Japanese Patent Laid-Open Publication No. 133634/1987 and 133633/1987. A first conventional photoelectron emitting structure disclosed in Japanese Patent Laid-Open Publication No. 133633/1987 has the energy band shown in FIG. 1. A narrow-energy gap film 6 has a sufficient thickness (below 300 Å) to absorb incident photons and generate photoelectrons. A wide-energy gap film 7 is thin (below 45 Å) enough to pass photoelectrons by the tunnel effect. The films 6, 7 are alternately laid one on the other in a photoelectron emitting structure. This photoelectron emitting structure uses the effect that the alternate superposition of two kinds of films increases a photoabsorbing coefficient for the incident photons in comparison with that of a conventional photoabsorbing layer consisted of homogeneous semiconductive materials. To efficiently lead photoelectrons generated by the incident photons to a photoemitting surface, a thickness of the wide-energy gap film 7 which is a barrier has to be thin enough, and practically has to be as thin as below 45 Å. Only those of the generated photoelectrons which have successfully passed the wider-energy gap film 7 owing to the tunnel effect arrive at the photoemitting surface to be emitted to a vacuum through a Cs_xO_y film 8 formed on the photoemitting surface. In this photoelectron emitting structure, the photoemission efficiency is achieved by absorbing the incident photons and generating electron-hole pairs between the valence band and the conduction band of the narrower-energy gap film 6. A second conventional photoelectron emitting structure disclosed in Japanese Patent Laid-Open Publication No. 133634/1987 has the energy band structure of FIG. 2. In the energy band structure of this photoelectron emitting structure a narrower-energy gap film 9 has a smaller film thickness than the film 6 of the first conventional photoelectron emitting structure. In this photoelectron emitting structure as well, the absorption of the incident photons, and the generation of electron-hole pairs take place between the valence band and the conduction band of the narrower-energy gap film 9, emitting photoelectrons from a Cs_xO_y film 11 for the improvement of photoemitting efficiency.

A long-wavelength photodetecting device using a quantum well structure is reported by B. F. Levine (Appl. Phys. Lett. 58(14) 1991). The band structure of the conduction band of this photodetecting device (a third conventional photoelectron emitting structure) is as shown in FIG. 3. Incident photons are absorbed between sub-bands of the conduction band formed in a narrow-energy gap film 12 which functions as the potential well, and photoelectrons are generated. In this case, the generated photoelectrons transfer through the X-valley of the conduction band of a wider-energy gap film 13 which functions as the potential barrier. In such photodetector, it is general that since the photoelectrons are detected as signals when they arrive at the electrode formed on the surface, electric fields formed inside the semiconductor device is small, and such photodetector is operated at biases as low as possible for suppressing noises as low as possible.

But the first conventional photoelectron emitting structure has an intrinsic problem. That is, as a thickness of the small-energy gap film 6 is decreased, subbands are formed due to the quantum effect both in the valence band and the conduction band, and a threshold for the incident photon absorption rises. As a result, incident long-wavelength photons cannot be absorbed.

In the second conventional photoelectron emitting structure, because of the thinness of the narrow-energy gap film 9, an energy difference E_{sg} between a sub-band of the valence band and a sub-band of the conduction band is larger than a band gap E_g, and as a result, an absorbed threshold wavelength of the incident photons is short.

In the third conventional photoemitting surface (the photodetecting device), as high dark currents is generated, the photoemitting surface has to be used at a remarkably low temperature by cooling down with liquid nitrogen or the like. As a result, it is difficult to be used in a general device as used at a room temperature.

SUMMARY OF THE INVENTION

This invention is made for the purpose of solving the above-described problems. In the photoelectron emitting structure according to this invention, photoelectrons are emitted from a emitting surface by incident photons on a photoabsorbing layer, which is formed of a semiconductor multi-layer comprising a plurality of semiconductor films including a first semiconductor film and a second semiconductor film. The first semiconductor film with a narrow energy gap is formed in a thickness of below 300 Å which allows an electron state to be quantized. The second semiconductor film with a wide energy gap is formed in a thickness of above 45 Å which does not allow electrons to pass the second semiconductor film owing to the tunnel effect. The absorption of the incident photons and the generation of electron-hole pairs takes place between sub-bands of a conduction band or between a sub-band and a bottom of the conduction band of said first semiconductor film with the narrow energy gap, generated photoelectrons are accelerated by an internal electric field to transit to a higher energy band.

The photoelectrons which have been excited to a lowest energy level of the conduction band are energized to transit to a higher energy level, and are accelerated by the internal electric field.

An energy difference between lowest energy levels of the conduction bands formed in the respective semiconductor films making up the semiconductor multi-layer is smaller than a narrowest energy gap among energy gaps between bands of the respective semiconductor films themselves.

According to this invention, the absorption of the incident photons, and the generation of photoelectrons take place between the sub-bands of the conduction band of the first semiconductor film, or between the bottom of the conduction band and the sub-band. As a result, the photoelectron emitting structure has a sensitivity to the incident light of longer wavelengths than wavelengths corresponding to an energy gap of the used semiconductors. The generated photoelectrons are accelerated by an inside electric field to be easily emitted into a vacuum.

Accordingly, the photoelectron emitting structure according to this invention has much improved sensitivity in comparison with the conventional photoelectron emitting structures, and it is possible to set its threshold wavelength at a much longer wavelength.

Electron tubes using such photoelectron emitting structure are operative up to relatively high temperatures, and in comparison with the conventional photoelectron emitting structures, such photoelectron emitting structure exhibits very high sensitivity especially in a long-wavelength range.

Optional designs of the kinds and structure of the semiconductor multi-layer constituting the photoabsorbing layer of the photoelectron emitting structure according to this invention make the photoelectron emitting structure sensitive to a wide range from long to short wavelengths.

The present invention will become more fully understood from the detailed description given hereinbelow and the accompanying drawings which are given by way of illustration only, and thus are not to be considered as limiting the present invention.

Further scope of applicability of the present invention will become apparent from the detailed description given hereinafter. However, it should be understood that the detailed description and specific examples, while indicating preferred embodiments of the invention, are given by way of illustration only, since various changes and modifications within the spirit and scope of the invention will become apparent to those skilled in the art form this detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a view of the band structure of the first conventional photoelectron emitting structure.

FIG. 2 is a view of the band structure of the second conventional photoelectron emitting structure.

FIG. 3 is a view of the band structure of the third conventional photoelectron emitting structure.

FIG. 4 is a sectional structural view of the photoelectron emitting structure according to one embodiment of this invention.

FIG. 5 is a view of a band structure of the photoelectron emitting structure according to the embodiment of FIG. 4 with no bias applied to.

FIG. 6 is a view of a band structure of the photoelectron emitting structure according to the embodiment of FIG. 4 with a bias applied to.

FIG. 7 is a sectional view of a side-on photomultiplier using the photoelectron emitting structure according to this invention.

FIG. 8 is a sectional view of a head-on photomultiplier using the photoelectron emitting structure according to this invention.

FIG. 9 is a sectional view of an image intensifier using the photoelectron emitting,structure according to this invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The photoelectron emitting structure according to one embodiment of this invention will be explained with reference to FIG. 4.

A photoabsorbing layer 22 is formed on a P^+-GaAs substrate 21. The photoabsorbing layer 22 comprises 40 undoped GaAs films of a 30 Å-thickness 22a and 40 $Al_{0.65}Ga_{0.35}As$ films of a 500 Å-thickness 22b, and forms heterojunctions. In FIG. 4 the heterojunctions are partially shown. A P^-GaAs contact layer 23 is formed in a thickness of 3000 Å on the photoabsorbing layer 22. An Al Schottky electrode 24 is mesh-patterned on the surface of the P^-GaAs contact layer 23. On the surface of this P^-GaAs contact layer 23 there is formed a very thin CsxOy film 25 by activating with Cs and O_2 for the reduction of a work function of the photemitting surface. An ohmic electrode 26 is formed on the underside of the P-GaAs substrate 21. A constant bias voltage is supplied by a power source 27 between the Schottky electrode 24 and the ohmic electrode 26.

FIG. 5 shows the band structure of the photoelectron emitting structure according to this embodiment with no bias voltage applied to. The respective layers in FIG. 5 has the same reference numerals as their corresponding layers in FIG. 4.

In this band structure, an energy difference between the conduction band of film 22a and the conduction band of film 22b is smaller than a minimum energy gap of the used semiconductors (undoped GaAs and $Al_{0.65}Ga_{0.35}As$) of the films 22a, 22b. Since each GaAs film 22a, which is a first semiconductor film, has a thickness of below 300 Å an electron state of which is quantized, the film 22a sandwiched by adjacent ones of the films 22b of $Al_{0.65}Ga_{0.35}As$, which is a second semiconductor film, functions as a potential well. Sub-bands are formed in each GaAs film 22a corresponding to a quantum level. At this time, since each $Al_{0.65}Ga_{0.35}As$ layer 22b has a thickness above 45 Å which does not allow electrons to pass therethrough owing to the tunnel effect, the sub-bands in the film 22a are always filled with bound electrons.

The photoelectron emitting structure according to this embodiment is intended to further excite the bound electrons to sub-bands of other quantum levels by the absorption of the incident photons. It is evident that the photoelectron emitting structure according to this embodiment is intrinsically different from the conventional photoelectron emitting structure consisted of homogeneous semiconductive materials, the first conventional photoelectron emitting structure disclosed in Japanese Patent Laid-Open Publication No. 133633/1987, and the second conventional photoelectron emitting structure disclosed in Japanese Patent Laid-Open Publication No. 133634/1987, in which the absorption of the incident photons and the generation of photoelectrons are performed between the valence band and the conduction band. Accordingly the conventional photoelectron emitting structures are totally insensitive to the incident photons of wavelengths longer than $\lambda=1.24/E_g$ which corresponds to an energy gap of the used semiconductors. But the photoelectron emitting structure according to this embodiment is sensitive to even to the incident photons of longer wavelengths than an energy gap of the used semiconductors. The wavelengths can be optionally varied by suitably designing the heterojunction of the semiconductor multi-layer of the photoabsorbing layer 22.

FIG. 6 shows the band structure of the photoelectron emitting structure according to this embodiment with a bias voltage applied to. In FIG. 6 as well the respective layers corresponding to the layers in FIG. 4 have the same reference numerals.

The photoelectrons generated between the sub-bands of the conduction bands of the GaAS films 22a of the photoabsorbing layer 22 by incident photons $h\nu$ transfer to X valleys which are the bottoms of the conduction bands of the $Al_{0.65}Ga_{0.35}As$ film 22b, which are a most lowest energy level. But since a 4 V-bias voltage is applied between the electrodes spaced from each other by 2.5 μm, and an electric field as high as about 1.6 KV/cm is formed, the generated photoelectrons are accelerated to immediately transit to Γ valleys which are higher energy bands. In this embodiment, where the $Al_{0.65}Ga_{0.35}As$ film 22 b is an indirect transition semiconductor, such X-Γ transition takes place. Needless to say, when a direct transition semiconductor is used, the Γ-X transition or Γ-L transition takes place. These photoelectrons which have been thus accelerated by an internal electric field and transit to higher energy bands can arrive at the photoemitting surface without dropping into the potential wells of the GaAs films 22a because potential energies of the photoelectrons are retained sufficiently high when photoelectrons traverse the heterojunctions. A very small number of the photoelectrons which have arrived at the photoemitting surface are attracted to the Schottky electrode 24, but most of those photoelectrons pass through the electrode pattern and through a Cs_xO_y film 25 to be emitted into a vacuum. At this time as potential energies of the photoelectrons are retained sufficiently high, the photoelectrons are efficiently emitted into a vacuum especially.

It is possible that the voltage to be applied between the electrodes is about 8 V to make an electric field as intense as about 3.2 KV/cm. The formation of an internal electric field in a range of 1 KV $\sim$ 55 KV/cm can cause the photoelectrons as mentioned above to be efficiently emitted into a vacuum. As described above, in the photoelectron emitting structure according to this embodiment, the photoelectrons generated by the incident photons between the sub-bands of the conduction band are accelerated by an internal electric field to transit the generated photoelectrons to higher energy bands and emit into a vacuum. That is, the photoelectron emitting structure according to this invention has an intrinsically different mechanism from, e.g., the photodetecting device reported by B. F. Levine et al. which uses the above-described third conventional quantum well, and in which photoelectrons are not accelerated by an internal electric field. In other words, in the photoelectron emitting structure according to this invention,an excitation of the incident photoelectrons takes place not between the so-called inter-bands of the valence band and the conduction band as conventionally, but between the sub-bands of the conduction band. Accordingly the photoelectron emitting structure according to this invention can be sensitive to long-wavelength light without the use of semiconductors of narrow energy gaps. Furthermore, the generated photoelectrons are accelerated by an internal electric field, and the photoelectrons which have fallen into the X valleys transit to the Γ valleys which have higher energy levels, after that the photoelectrons are emitted into a vacuum. As a result, as described above, the potential energy of the photoelectrons is higher than that of the conventional photoelectron emitting structures, and the generated photoelectrons can be excited to be efficiently emitted into a vacuum. Thus, the photoelectron emitting structure according to this invention has a very high sensitivity in comparison with that of the photoelectron emitting structures using the conventional structure of semiconductors. The photoelectron emitting structure according to this invention can set its wavelength limit at a very long wavelength. Furthermore, suitable designs of the kinds and structure of the heterojunction semiconductor multi-layer of the heterojunctions providing the photoabsorbing layer 22 can provide a photoelectron emitting structure which has a photodetecting characteristic having a peak at an optional wavelength. The photoelectron emitting structure according to this invention has high degrees of freedom of making choices of the semiconductor multi-layer in kinds, thicknesses and numbers of the semiconductor films, and accordingly can have the sensitivity adjusted to an optional one from a wide to a narrow range.

The secondary electron multiplication of the photoelectrons emitted into a vacuum makes it possible to provide long-wavelength photodetecting devices of high sensitivities and low noises which are operative at relatively high temperatures. That is, the photoelectron emitting structure according to the above-described embodiment is effectively applicable to electron tubes. In the application of a photocathode in photomultipliers, the photoelectron emitting structure according to the above-described embodiment is used as the photoelectric transfer surfaces, i.e., a photoemitting surface. The photoelectrons emitted from the photoemitting surface are secondary electron multiplied by the dynodes, and groups of the multiplied secondary electrons are detected by the anodes. In its application to image tubes the photoelectron emitting structure according to the above-described embodiment is used as a photoemitting surface in the image inputting units. The photoelectrons emitted from the photoemitting surface are focused by the electron lenses, and an image is formed on the phosphorous surface. The photoelectron emitting structure according to the above-described embodiment is applicable also to image intensifiers (I·I tubes) in which photoelectrons converged by the electron lenses are multiplied by the microchannel plates (MCPs). In its application to photo tubes, the photoelectron emitting structure according to the above-described embodiment is used as a photodetecting surface. The photoelectrons emitted from the photodetecting surface are detected by the anodes.

FIGs. 7, 8 and 9 show electron tubes each using the photoelectron emitting structure according to this invention. FIG. 7 is a sectional view of a side-on photomultiplier using a reflection-type photoemitting surface. FIG. 8 is a sectional view of a head-on photomultiplier using a transmission-type photoemitting surface. FIG. 9 is a sectional view of an image intensifier using a transmission-type photoemitting surface.

The photomultiplier of FIG. 7 includes in a vacuum vessel 71 a photoemitting surface 72, a plurality of dynodes 73, and an anode 74. On the front of the photoemitting surface 72 there is provided a mesh electrode 75. In the photomultiplier of FIG. 8, there is mounted a photoemitting surface 72 on one end of a vacuum vessel 71, and a focusing electrode 76 is provided in the vacuum vessel 71. In these respective photomultipliers photoelectrons (e^-) are emitted by incident photons $h\nu$, and the photoelectrons are multiplied by the dynodes 73 and detected by the anode 74.

In the image intensifier of FIG. 9, a photoemitting surface 72 is secured to the opened front of a cylindrical bulb 81, and an glass output face plate 82 with a phosphorous film 83 applied to the inside thereof is secured to the opened rear end of the cylindrical bulb 81. Inside the cylindrical bulb 81 there is provided a microchannel plate 84.

These respective electron tubes using the photoelectron emitting structure according to this invention has a very high sensitivity especially in a long-wavelength range in comparison with the conventional electron tubes. Accordingly such electron tubes are very effective in the photometry, imaging, etc. at low illuminance.

In the above-described embodiment, the photoabsorbing layer 22 as the semiconductor multi-layer is formed of the heterojunction of the GaAs film 22a and Al0.65Ga0.35As film 22b but is not essentially limited to the heterojunction of these semiconductors. Other III-V compound semiconductors, or Si, Ge and their mixed crystal may be used. The kinds of the semiconductors are not essentially limited to two.

For example, the photoabsorbing layer 22 may be formed of GaAs films and AlAs films, or their mixed crystal. InP films and InGaAs films, or their mixed crystal may be used. InP films and AlGaAs films, or their mixed crystal may be used.

The formation of the photoabsorbing layer 22 of these materials can produce the same effects as in the above-described embodiment. Furthermore, the photoabsorbing layer may be formed of semiconductor multi-layer of the same kind having a p-n-i junction. In such case the same effects as those produced by the above-described embodiment can be achieved.

In the above-described embodiment, the Schottky electrode 24 is formed of Al, but the kind of the material of the Schottky electrode 24 is not specifically limited as long as the material is a metal which can form a good Schottky junction with used semiconductors. Its pattern can be optional.

The Schottky electrode 24 may be formed of, e.g., Ag, Au, Pt, Ti, W, Cr, WSi or alloys of these metals. The Schottky electrode of these metals can produce the same effects as those produced by the above-described embodiment.

In the above-described embodiment, the Cs_xO_y film 25 is applied to the photoemitting surface of the photoelectron emitting structure for the reduction of the work function but the Cs_xO_y film 25 is not essential. The film 25 may be formed of an alkali metal such as K, Na, Rb, Bi, Cs or others, or a compound, an oxide or a fluoride of any one of these metals.

These materials also can reduce the work function of the photoemitting surface.

From the invention thus described, it will be obvious that the invention may be varied in many ways. Such variations are not to be regarded as a departure from the spirit and scope of the invention, and all such modifications as would be obvious to one skilled in the art are intended to be included within the scope of the following claims.

Claims

1. A photoelectron emitting structure for emitting therefrom photoelectrons generated by incident photons on a photoabsorbing layer,

   the photoabsorbing layer formed of a semiconductor multi-layer comprising a plurality of semiconductor films including a first semiconductor film and a second semiconductor film, the first semiconductor film with a narrow energy gap being formed in a thickness of below 300 Å which allows an electron state to be quantized, the second semiconductor film with a wide energy gap being formed in a thickness of above 45 Å which does not allow electrons to pass the second semiconductor film owing to the tunnel effect,

   the absorption of the incident photons and the generation of electron-hole pairs taking place between sub-bands of a conduction band or between a sub-band and the bottom of a conduction band, of said first semiconductor film with the narrow energy gap,

   generated photoelectrons being accelerated by an internal electric field to transit to a higher energy band.

2. A photoelectron emitting structure according to claim 1, wherein the photoelectrons which have been excited to a lowest energy level of the conduction band are energized to transit to a higher energy level, and are accelerated by the internal electric field.

3. A photoelectron emitting structure according to claim 1, wherein an energy difference between lowest energy levels of the conduction bands formed in the respective semiconductor films making up the semiconductor multi-layer is smaller than the narrowest energy gap of the respective semiconductor films themselves.

4. A photoelectron emitting structure according to claim 1, wherein the first semiconductor film and the second semiconductor film are formed of different materials from each other and constitute a heterojunction.

5. A photoelectron emitting structure according to claim 4, wherein the semiconductor film layer are formed of III-V compound semiconductors, or their mixed crystal.

6. A photoelectron emitting structure according to claim 5, wherein the III-V compound semiconductors are GaAs and AlAs.

7. A photoelectron emitting structure according to claim 5, wherein the III-V compound semiconductors are InP and InGaAs.

8. A photoelectron emitting structure according to claim 5, wherein the III-V compound semiconductors are InP and AlGaAs.

9. A photoelectron emitting structure according to claim 1, wherein the first semiconductor film and the second semiconductor films are formed of semiconductors of the same kind doped with different conduction impurities, and form a homojunction.

10. A photoelectron emitting structure according to claim 9, wherein the semiconductor films are formed of Si, Ge, or its mixed crystal.

11. A photoelectron emitting structure according to claim 1, wherein on a surface thereof there are formed an electrode for applying a required electric field to the photoabsorbing layer, and a metal film for reducing a work function of the photoemitting surface.

12. A photoelectron emitting structure according to claim 11, wherein the electrode is in Schottky contact with the photoemitting surface.

13. A photoelectron emitting structure according to claim 12, wherein the electrode is formed of Al, Ag, Au, Pt, Ti, W, Cr or WSi, or a metal alloy of any one of these materials.

14. A photoelectron emitting structure according to claim 11, wherein the metal film is formed of K, Na, Rb, Bi or Cs, or a metal compound, an oxide or fluoride of any one of these materials.

15. An electron tube comprising a photoelectron emitting structure according to any one of claims 1 to 3.

16. A photodetector comprising an electron tube according to claim 15.

17. A photoelectron emitting device for emitting electrons in accordance with incident photons, comprising:

a semiconductor substrate;

a semiconductor multi-layer comprising a plurality of semiconductor films including a first semiconductor film and a second semiconductor film, the first semiconductor film with a narrow energy gap having a thickness of below 300 Å, and the second semiconductor film with a wider energy gap having a thickness of above 45 Å;

a front surface electrode formed on the semiconductor multi-layer;

a photoemitting unit including a backside electrode formed on the backside of the semiconductor substrate; and

internal electric field generating means for applying a voltage between the front surface electrode the backside electrode to generate an internal electric field in the semiconductor multilayer.

18. A method for using a photoemitting device comprising:

a semiconductor substrate;

a semiconductor multi-layer comprising a plurality of semiconductor films infuding a first semiconductor film and a second semiconductor film, the first semiconductor film with a narrow energy gap having a thickness of below 300 Å, and the second semiconductor film with a wider energy gap having a thickness of above 45 Å;

a front surface electrode formed on the semiconductor multi-layer;

a photoemitting unit including a backside electrode formed on the backside of the semiconductor substrate; and

internal electric field generating means for applying a voltage between the front surface electrode the backside electrode to generate an internal electric field in the semiconductor multilayer, the method comprising:

applying a voltage between the front surface electrode and the backside electrode to generate an internal electric field in the semiconductor multi-layer, absorbing incident photons and generating electron-hole pairs between subbands of a conduction band of the energy band or between a sub-band and a bottom of the conduction band, of said first semiconductor film with a narrow energy gap, accelerating the generated photoelectrons by the internal electric field generated by the applied voltage to cause the photoelectrons to transit a higher energy band to be emitted.

19. A photoelectron emitting structure comprising a photon-absorbing layer (22) comprising a stack of semiconductor layers, each semiconductor layer comprising a first semiconductor film (22a) having a relatively narrow energy gap and a thickness of less than 300Å and a second semiconductor film (22b) having a relatively wide energy gap and a thickness of more than 45Å, the structure further comprising means (24,26) sandwiching the photon-absorbing layer (22) for the generation of an internal electric field.

Fig. 1

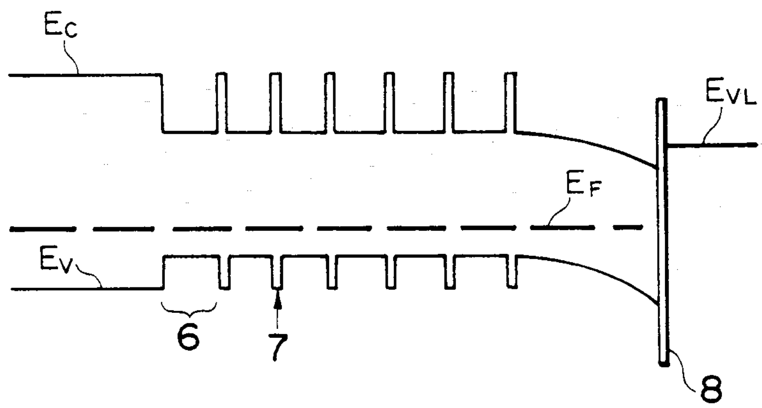


Fig. 2

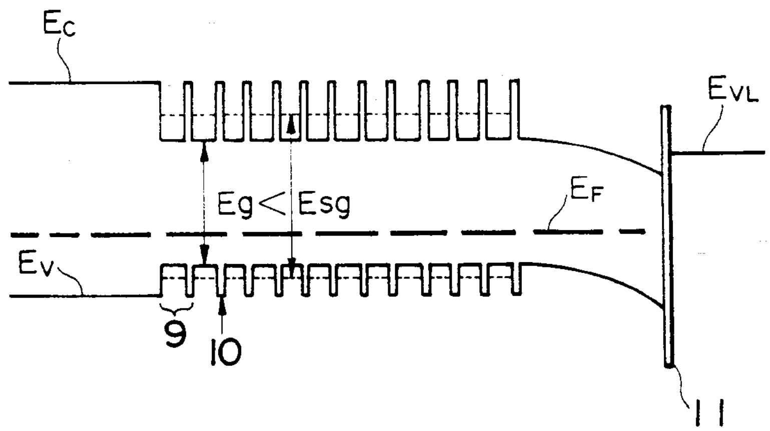


Fig. 3

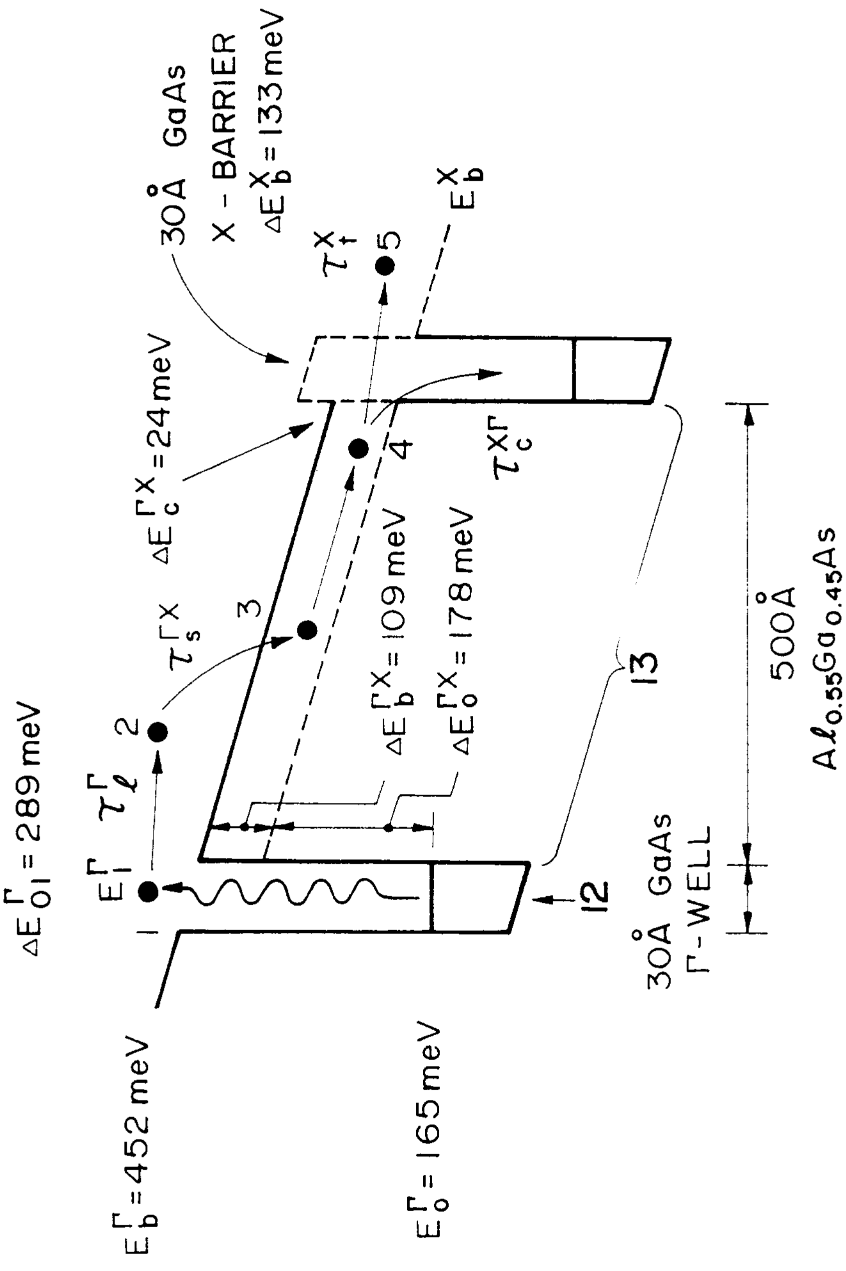

30Å GaAs
X - BARRIER
$\Delta E_b^X = 133\,meV$
E_b^X
τ_t^X
5
$\Delta E_c^{\Gamma X} = 24\,meV$
4
$\tau_c^{X\Gamma}$
$\tau_s^{\Gamma X}$
3
$\Delta E_b^{\Gamma X} = 109\,meV$
$\Delta E_o^{\Gamma X} = 178\,meV$
13
500Å
$Al_{0.55}Ga_{0.45}As$
$\Delta E_{01}^{\Gamma} = 289\,meV$
τ_ℓ^Γ
2
E_1^Γ
1
12
30Å GaAs
Γ-WELL
$E_b^\Gamma = 452\,meV$
$E_o^\Gamma = 165\,meV$

Fig. 4

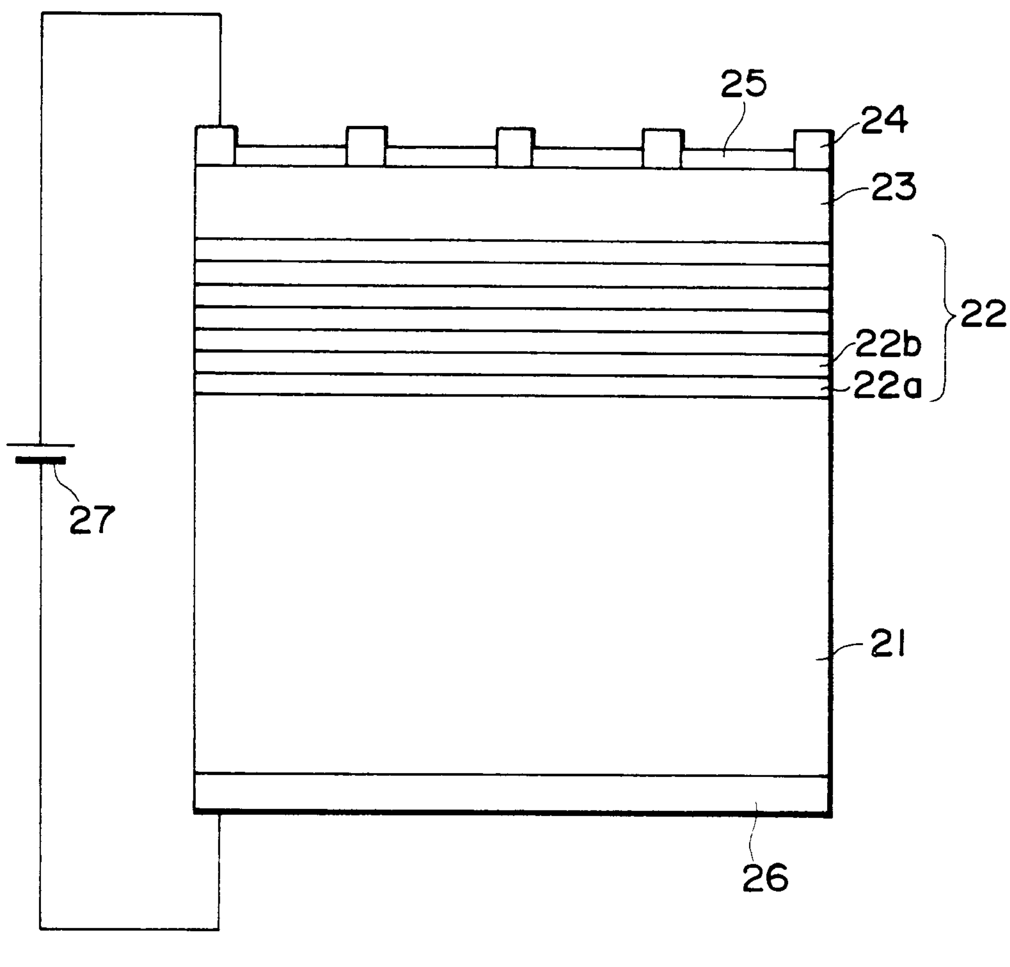


Fig. 5

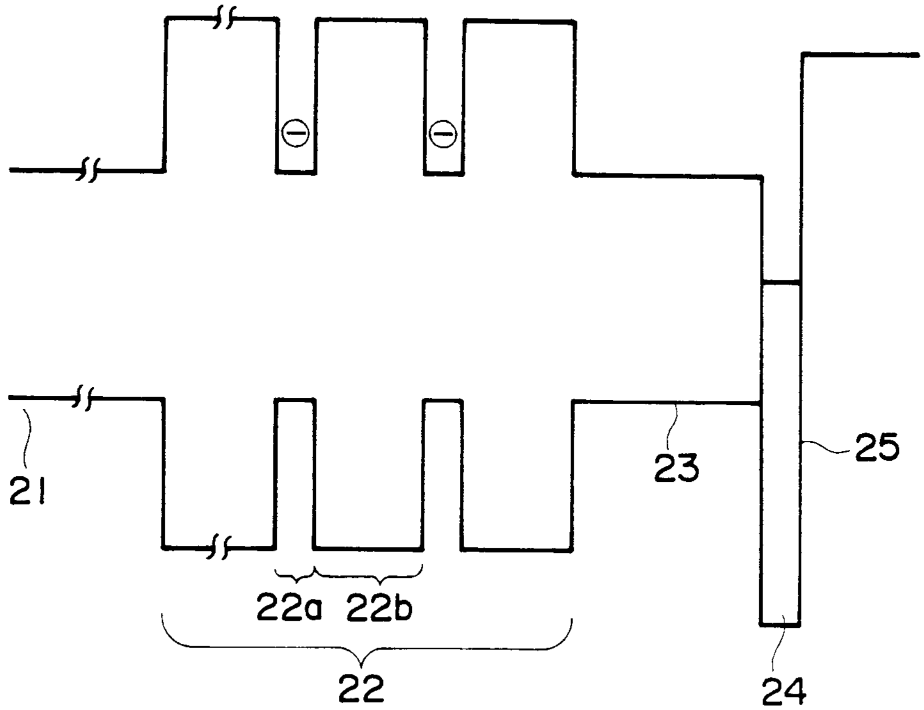


Fig. 6

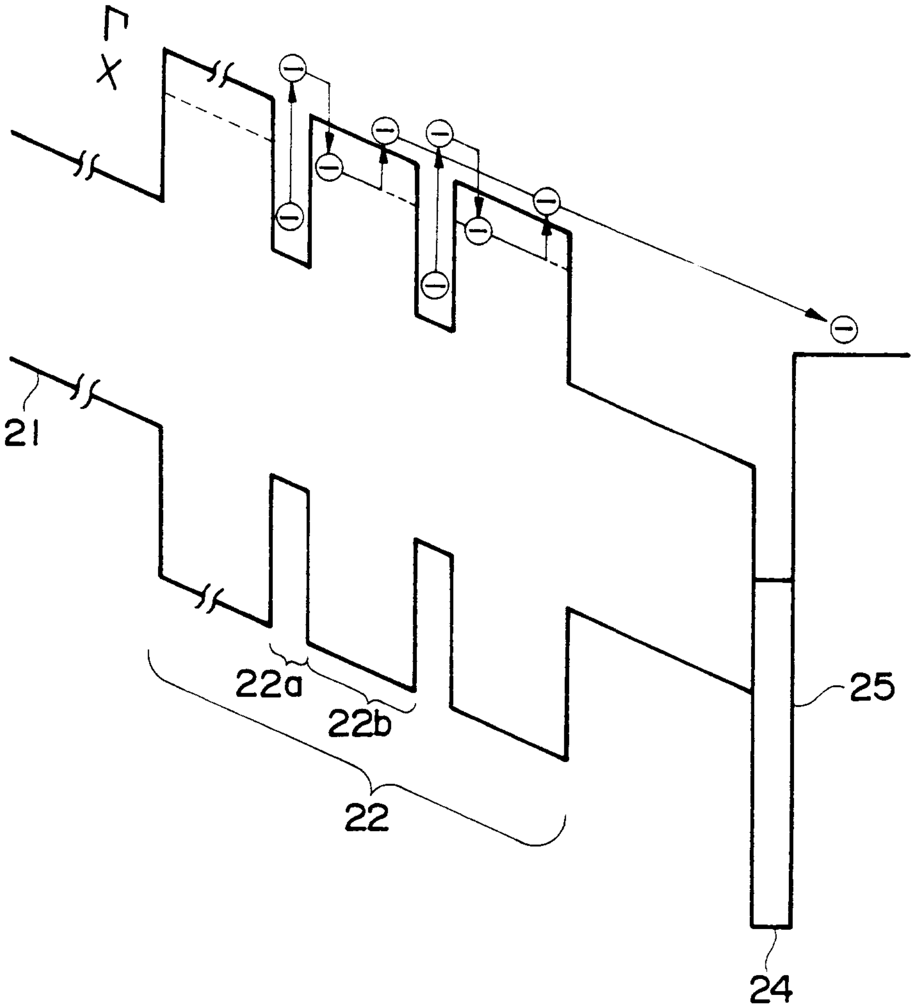


Fig. 7

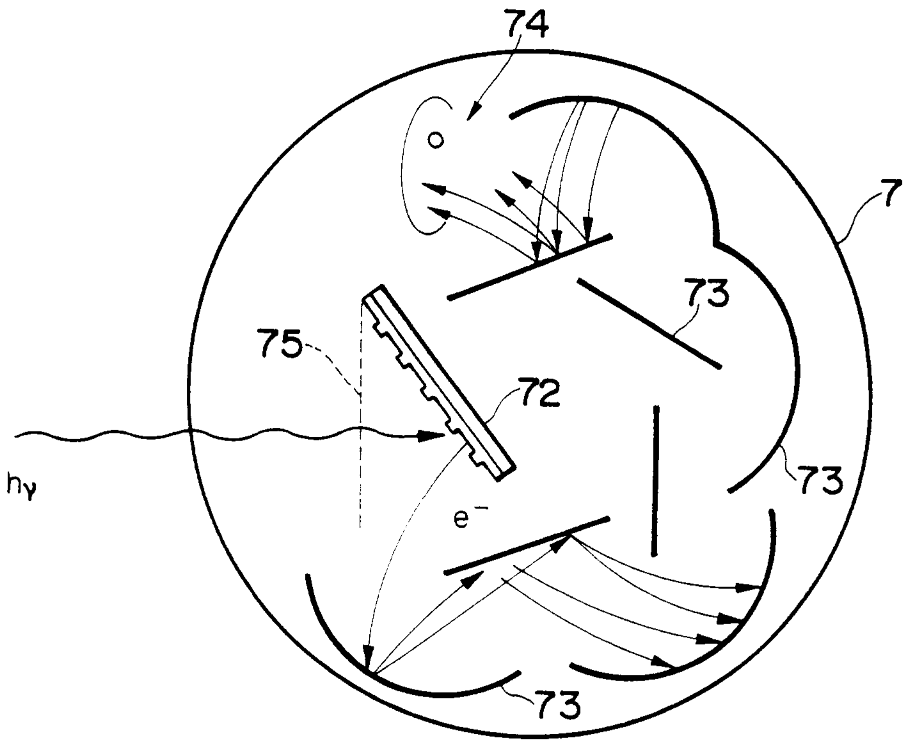


Fig. 8

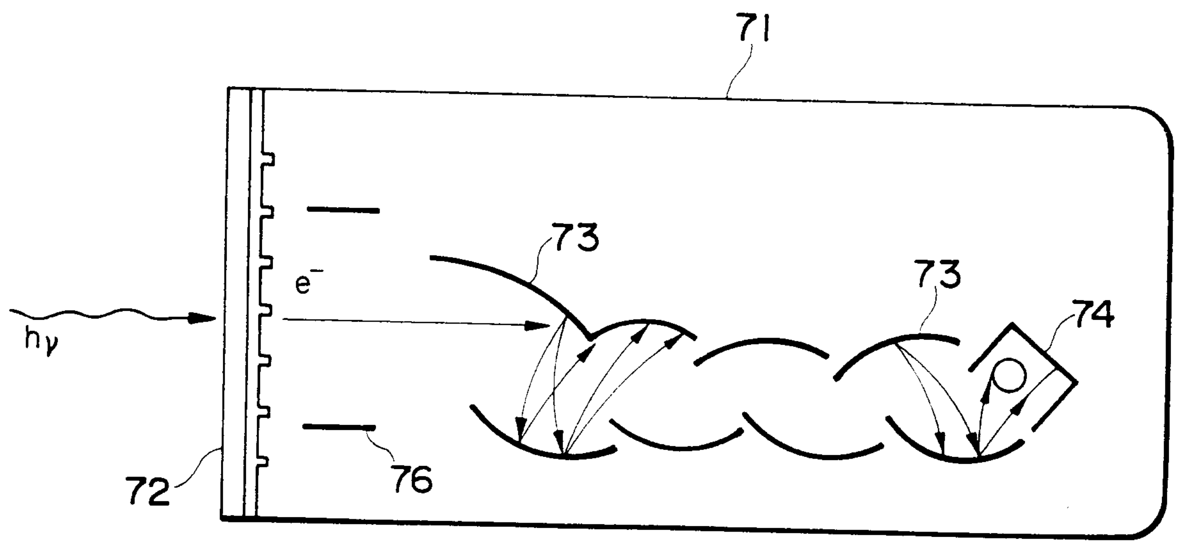
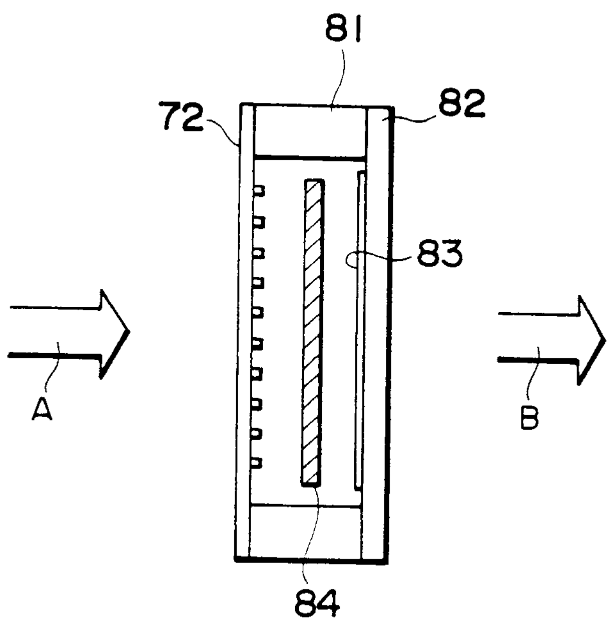


Fig. 9



European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 93 30 1385

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
A	GB-A-2 213 634 (THIRD GENERATION TECHNOLOGY LIMITED) * abstract * * page 6, line 20 - page 7, line 19 * ---	1,4-8, 17,18	H01J1/34 H01J40/06
A	US-A-4 015 284 (HARA ET AL.) * column 1, line 46 - line 54 * * column 2, line 19 - line 42 * ---	4	
D,A	US-A-4 749 903 (MUNIER ET AL.) * column 1, line 65 - column 2, line 14 * * column 2, line 49 - line 66 * * column 3, line 6 - line 23 * * column 4, line 3 - line 10 * * column 4, line 18 - line 25 * ---	1,17,18	
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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	14 APRIL 1993	COLVIN G.G.

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