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(54) **Reflection mode alkali photocathode, and photomultiplier using the same**

Reflexionsmodus-Alkali-Photokathode und Photovervielfacher der dieser verwendet

Photocathode alkaline et fonctionnant en mode réflexion et photomultiplicateur l'utilisant

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Description

This invention relates to a reflection mode alkali (bi-alkali or multialkali) photocathode, and a photomultiplier using it.

Conventional photocathodes are in the form of transmission mode photocathodes which emit electrons in the direction opposite to that of the incident light, i.e., incident photons are converted into photoelectrons and transmitted, or of reflection mode photocathodes which emit photoelectrons towards the incident light, i.e., incident photons are converted into photoelectrons and emitted back towards the incident light. The reflection mode photocathode comprises a base substrate, generally of a metal. Reflection mode bialkali photocathodes and reflection mode multialkali photocathodes having a base substrates of nickel (Ni) are known. In the reflection mode bialkali photocathode, antimony (Sb) is deposited on the Ni base substrate and is activated by potassium (K) and cesium (Cs). In the multialkali photocathode, Sb is deposited on a Ni base substrate and is activated by K, Cs and sodium (Na). The amount of Sb deposition has generally been above 200 $\mu\text{g}/\text{cm}^2$, as will be explained below.

EP-A-05 32 358 (which falls within the terms of Article 54(3) EPC) describes a reflection type photocathode for use in a photomultiplier tube formed by sequentially depositing three layers on a nickel substrate. The first layer is made of chromium, manganese or magnesium as a major component and is deposited over the substrate. The second layer is made of aluminium as a major component and is deposited over the first layer. The third layer is made of antimony and at least one kind of alkali metal and is deposited over the second layer.

"S-11 and S-20 photocathode research activity" by F. Gex et al., Proc. SPIE-The International Society For Optical Engineering, 1985, USA, SPIE vol 491, pages 287-293, described a reflection type photocathode formed by depositing upon a glass substrate a metal comprising aluminium and nickel amongst others. Upon this metal is deposited an antimony activated alkali photocathode of up to 90 nm thickness.

In the above-mentioned conventional reflection mode alkali photocathodes, e.g., bialkali photocathodes, their radiant sensitivity S_k is about 80 $\mu\text{A}/\text{Lm}$. Even in a reflection mode bialkali photocathode having an intermediate layer between the Sb layer and the base substrate, maximum radiant sensitivity S_k is 120 $\mu\text{A}/\text{Lm}$. Here $\mu\text{A}/\text{Lm}$ represents sensitivity in lumens. Lumen is a unit of luminous flux based on visual sensitivity, and 1 $\text{Lm}/\text{m}^2 = 1 \text{ Lux}$. The radiant sensitivity S_k corresponds to a current density of the photocathode when the intensity of incident light is expressed in Watts.

Photomultipliers are used in the field of measuring feeble light. The beneficial properties of the photomultiplier are apparent in the limiting case where the light to be detected is counted in photons. Accordingly, even some small percentage of sensitivity improvement is

significant.

From this viewpoint, the inventors have found that a good reflection mode alkali photocathode can be realized by controlling the deposition weight of Sb.

The reflection mode alkali photocathode according to this invention comprises a thin layer of antimony deposited directly on a base substrate, and activated by a plurality of alkali metals, in which the thin layer of antimony is deposited in an amount below 100 $\mu\text{g}/\text{cm}^2$ and activated by the alkali metals. The reflection mode alkali photocathode according to this invention is suitably usable in photomultipliers.

In the reflection mode alkali photocathode according to this invention, the layer of Sb activated by the alkali metals is deposited sufficiently thin. This is a drastic change from the conventional idea embodied in conventional reflection mode photocathodes. That is, a reduction from the 200 $\mu\text{g}/\text{cm}^2$ deposition amount of the conventional Sb layer of the conventional reflection mode photocathode to below 100 $\mu\text{g}/\text{cm}^2$ can produce sufficiently satisfactory results.

Attempts to improve the photosensitivities of photocathodes including Sb have included the selection of materials of the base substrate of the photocathode surface, the improvement of the surface treatment of the photocathode, and the fabrication conditions, such as temperature and degree of vacuum for activating the photocathode surface with alkali metals.

The inventors have noticed that the deposition weight of Sb is completely different from previous devices and made studies on it.

The finding is that photosensitivities of the photocathode are very dependent on the deposition weights of Sb. Analysis by electronic balance of the deposition weights of the Sb content of photomultipliers (hereinafter called "PMT") marketed by Hamamatsu Photonics K.K. have shown that the deposition weights of reflection mode photocathode of both multialkali and bialkali types are about 200 $\mu\text{g}/\text{cm}^2$.

PMTs having various Sb deposition weights were then fabricated and the deposition weight dependency of the radiant sensitivity was studied. The finding was that the photocathode of these PMTs have peak photosensitivities at about 40 $\mu\text{g}/\text{cm}^2$ and are superior to the conventional photocathodes.

The inventors have therefore demonstrated experimentally that sufficient radiant sensitivity can be obtained with a Sb deposition weight range of 10 $\mu\text{g}/\text{cm}^2$ - 100 $\mu\text{g}/\text{cm}^2$. As for radiant sensitivities at below 10 $\mu\text{g}/\text{cm}^2$, by extrapolating data of the experiments, radiant sensitivities of the fabricated PMTs more than that of the conventional PMTs can be obtained at, e.g., even some $\mu\text{g}/\text{cm}^2$. Even in the case when the base substrate of the photocathode surface is formed of aluminium (Al), high photosensitivities can be obtained even in a range of 5 $\mu\text{g}/\text{cm}^2$ - 10 $\mu\text{g}/\text{cm}^2$.

The Sb deposition weights were quantitatively determined by the following method.

Antimony (Sb) can be deposited on a nickel plate functioning as the base substrate by, e.g., the following method. First, a target made of Sb is placed on a heater as the evaporation source in a vacuum vessel. Eight sheets of nickel plates are set respectively at the same distance from the evaporation source. Then, the heater is turned on to vaporize the Sb. Then based on a vaporizing amount of the Sb from the heater and a distance from the evaporation source to the nickel plates, a deposition weight of the Sb per unit area can be easily given.

The evaporation of the Sb is not always uniform in all directions, and the evaporation of all the Sb is not assured. Accordingly it is difficult to measure an accurate deposition weight by the above-described indirect method. Then, to improve the reliability of the tests, the following direct method was used.

An evaporation source was prepared including a wire heater 101 and Sb target adhered to the wire heater. The wire heater 101 was vertical as shown in FIG. 1. Eight nickel plates 201 - 208 were set upright on an evaporation ring 102 which was rotatable around the wire heater 101. The respective nickel plates 201 - 208 were positioned at the same distance from the wire heater 101. A direct current was supplied to the wire heater through electrodes 103, 104 and the evaporation ring 102 was rotated so that the Sb was slowly evaporated. Thus the Sb could be deposited evenly on all the nickel plates 201 - 208.

A deposition weight of the Sb was measured as follows. Weights of the 8 sheets of nickel plates before the deposition were measured by an electronic balance type measurement device of high precision with the zero point adjusted. Then the Sb was evaporated by the method of FIG. 1. The deposition weight could be controlled with high precision by adjusting the amount of solid Sb on the wire heater, and also by adjusting evaporation times or heating temperatures with the wire heater. Then the 8 nickel plates with the deposited Sb were measured by the electronic balance type measurement device with the zero point adjusted.

A deposition weight of the Sb per unit area could be determined based on differences of weights of the measured nickel plates before and after deposition, and the deposition areas of the nickel plates. The data of FIGs. 2, 3 and 4 were thus obtained.

The base substrate, which is in direct contact with the Sb thin layer, is formed of, e.g., Ni, Al or stainless steel. K, Ca, Rb and Na are suitable as the alkali metals. Thus a reflection mode alkali photocathode of high radiant sensitivity can be realized with high yields.

The present invention according to claim 1 will become more fully understood from the detailed description given below and the accompanying drawings which are given by way of illustration.

In the accompanying drawings.

FIG. 1 is a view of the device for evaporating Sb used by the inventors for high precision measure-

ment of the deposition weights of Sb;

FIG. 2 is a graph of the radiant sensitivity characteristic of one bialkali photocathode fabricated for the tests;

FIG. 3 is a graph of the radiant sensitivity characteristic of another bialkali photocathode fabricated for the tests;

FIG. 4 is a graph of the radiant sensitivity characteristic of one of the multialkali photocathode surfaces fabricated for the tests;

FIG. 5 is a side view of a side-on PMT with the glass bulb partially broken; and

FIG. 6 is a sectional view of the PMT of FIG. 5 along the line $X_1 - X_2$.

The reflection mode alkali photocathode according to this invention comprises a base substrate of Ni, Al or stainless steel plate and a photosensitive layer containing Sb activated by alkali metals, such as cesium (Cs), potassium (K), sodium (Na) and rubidium (Rb). The deposition weight of Sb is below $100 \mu\text{g}/\text{cm}^2$.

A photomultiplier having such reflection mode alkali photocathode is fabricated as follows. A glass vacuum vessel is prepared, and Sb is evaporated on the part on which the reflection mode photocathode is to be formed. Sb is deposited as a thin film in a deposition weight of below $100 \mu\text{g}/\text{cm}^2$. Subsequently when the photocathode surface portion is of a bialkali, Cs, Na and/or K are introduced to activate the photocathode surface and the photocathode is sintered. Temperature conditions and times for activation and sintering are known. Generally, the temperature is selected from $140 - 220^\circ\text{C}$.

The other components of the photomultiplier (PMT), such as dynodes, microchannel plates, anode, etc. are mounted in the conventional procedure. When the reflection mode alkali photocathode is formed, and the other components are assembled the vacuum vessel is closed, and the reflection mode alkali photocathode is finished.

One structure of a photomultiplier containing a reflection mode alkali photocathode according to this invention is shown in FIGs. 5 and 6. As shown in FIG. 5, a glass bulb 2 is mounted on a support 1, and stem pins 3A - 3F are provided extending downwardly from the support 1. As shown in the sectional view along the line $X_1 - X_2$ of FIG. 5, the glass bulb 2 houses a cathode 4 of a nickel base substrate with a photocathode surface formed on it, a metal mesh electrode 5 provided on the front surface of the glass bulb 2, a circular cage-type 9-stage dynodes 61 - 69, and an anode 7. In this PMT light passing the metal mesh electrode 5 enters the cathode 4. Photoelectrons thus emitted impinge on the respective dynodes 61, 62, ..., ..., 68, 69 one after another, and the number of electrons is rapidly increased by the emission of secondary electrons. Then all the electrons are collected by the anode 7 and are transmitted as electric signals through one of the stem pins 3A - 3F.

Next, examples of fabrication for tests of the bialkali

photocathode surface will be explained. In all the examples the conditions, such as temperatures, vacuum degrees, times, etc. are the same irrespective of deposition weights of Sb. In the examples, base substrates were Ni plates having their surfaces (weakly) oxidized, and Sb layers were formed on the washed oxidized surfaces.

In the examples, the Sb layers were deposited in 6 different thicknesses (deposition weights) from 15 - 230 $\mu\text{g}/\text{cm}^2$. Then K and Cs were introduced to activate the Sb layers to obtain a bialkali (K-Cs-Sb) photocathode. Twenty photocathode surfaces (totally 120) were prepared at the respective set deposition weights.

The sample photocathode surfaces exhibited the radiant sensitivity characteristic of FIG. 2. The average luminous sensitivity was below about 80 ($\mu\text{A}/1\text{m}$) at a deposition weight of Sb of above 100 $\mu\text{g}/\text{cm}^2$. At a deposition weight of 20 - 80 $\mu\text{g}/\text{cm}^2$, the average luminous sensitivity was above 115 ($\mu\text{A}/1\text{m}$).

As apparent in FIG. 2, the deposition of Sb in 40 $\mu\text{g}/\text{cm}^2$ provides especially good improvement of the radiant sensitivity. The sample photocathode surfaces exhibited a maximum value of 193 $\mu\text{A}/1\text{m}$. A 150 $\mu\text{A}/1\text{m}$ radiant sensitivity could be stably realized. This high sensitivity widely ranged from near infrared radiation to ultraviolet radiation.

Furthermore, there were fabricated for test bialkali photocathode surfaces, using nickel, stainless steel and aluminium as the base substrates, and potassium, cesium, rubidium, etc. as the alkali metals.

Sample A: A nickel plate having the surface weakly oxidized was used, and K-Cs were used as the alkali metals.

Sample B: A nickel plate having the surface nonoxidized, and K-Cs were used as the alkali metals.

Sample C: A nickel plate having the surface oxidized, and Rb-Cs were used as the alkali metals.

Sample D: A stainless steel (non-magnetic material) plate which had undergone no oxidizing step, and K-Cs were used as the alkali metals.

Sample E: An aluminium plate which had undergone no oxidizing step, and K-Cs were used as the alkali metals.

Five PMTs were prepared for each of 10, 20, 50, 80 and 160 $\mu\text{g}/\text{cm}^2$ Sb deposition weights of each of Samples A, B, D and E. Three PMTs were prepared for each of the above-stated Sb deposition weights for Sample C. Average radiant sensitivities were determined.

The results are shown in FIG. 3. As shown in FIG. 3, in the cases where the base substrates are formed of nickel or stainless steel, high radiant sensitivities can be obtained at an Sb deposition weight of 10 - 100 $\mu\text{g}/\text{cm}^2$. In the case where the base substrate is formed of aluminium, a high sensitivity can be obtained at 5 - 100 $\mu\text{g}/\text{cm}^2$.

In further examples the base substrates were Al plates having Al deposited on the surfaces, and Sb layers were deposited on the washed surfaces of the Al

plates.

In the examples, the Sb layers were deposited in 7 different thicknesses (deposition weights) from 15 - 205 $\mu\text{g}/\text{cm}^2$. Then Na, K, Cs were introduced to activate the Sb layers to obtain multialkali (Cs-Na-K-Sb) photocathodes. Five photocathodes (totally 35) were prepared at the respective deposition weights.

The sample photocathode surfaces exhibited the radiant sensitivity characteristic of FIG. 4. The average luminous sensitivity was below about 120 ($\mu\text{A}/1\text{m}$) at a deposition weight of Sb of above 100 $\mu\text{g}/\text{cm}^2$. At a deposition weight of 20 - 80 $\mu\text{g}/\text{cm}^2$, the average luminous sensitivity was above 140 - 150 ($\mu\text{A}/1\text{m}$).

As apparent in FIG. 4, the deposition weight of Sb of about 40 $\mu\text{g}/\text{cm}^2$ can attain especially good improvement of the radiant sensitivities. In the examples, radiant sensitivities of about 200 $\mu\text{A}/1\text{m}$ can be stably realized. The high radiant sensitivities widely range from the near infrared to the ultraviolet. It is apparent from the examples and the test results that base substrates of nickel, stainless steel, aluminium or others can be used as the multialkali photocathode surfaces.

The alkali photocathode according to this invention includes the Sb layer in a deposition weight of below 100 $\mu\text{g}/\text{cm}^2$, whereby reflection mode alkali photocathode of a high sensitivity can be realized with high yields. As alkali metals used in the photocathode surface according to this invention, some elements other than cesium, potassium, rubidium and sodium are available. As the base substrate of the photocathode surface according to this invention, some metals other than aluminium, nickel and stainless steel are available. Although the inventors have not obtained experimental data on all combinations of these materials, the results of their experiments on combinations of typical materials showed characteristics common to the experiments, i.e., the Sb deposition weight dependency of the radiant sensitivity as shown in FIGs. 2-4.

Claims

1. A reflection mode alkali photocathode comprising
 - a base substrate of a nickel, aluminum or stainless steel plate; and
 - a layer containing antimony and a plurality of alkali metals formed directly on the base substrate, the deposition weight of the antimony on the substrate being above 10 and below 100 $\mu\text{g}/\text{cm}^2$.
2. A reflection mode alkali photocathode according to claim 1, wherein at least one of the alkali metals is sodium, potassium, rubidium or cesium.
3. A photomultiplier comprising

a reflection mode alkali photocathode according to claim 1 or claim 2;
electron multiplying means for multiplying photoelectrons emitted from the reflection mode alkali photocathode; and
an anode for collecting multiplied electrons.

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réflexion selon la revendication 1 ou la revendication 2 ;

des moyens multiplicateurs d'électrons pour multiplier les photoélectrons émis par la photocathode à métal alcalin à mode de réflexion ; et une anode pour recueillir les électrons multipliés.

Patentansprüche

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1. Reflexions-Alkali-Photokathode mit

einem Trägersubstrat aus einer Platte aus Nickel, Aluminium oder rostfreiem Stahl und einer Antimon und eine Vielzahl von Alkalimetallen enthaltenden Schicht, die direkt auf dem Trägersubstrat ausgebildet ist, wobei das Abscheidungsgewicht des Antimons auf dem Substrat mehr als 10 und weniger als 100 µg/cm² beträgt.

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2. Reflexions-Alkali-Photokathode nach Anspruch 1, wobei zumindest eines der Alkalimetalle Natrium, Kalium, Rubidium oder Cäsium ist.

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3. Photovervielfacher mit

einer Reflexions-Alkali-Photokathode gemäß Anspruch 1 oder 2,
einer Elektronenvervielfachungseinrichtung zur Vervielfachung von aus der Reflexions-Alkali-Photokathode emittierten Photoelektronen und
einer Anode zum Auffangen der vervielfachten Elektronen.

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Revendications

1. Photocathode à métal alcalin à mode de réflexion, comprenant :

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un substrat de base constitué d'une plaque de nickel, d'aluminium ou d'acier inoxydable ; et une couche contenant de l'antimoine et une pluralité de métaux alcalins formés directement sur le substrat de base, le poids de dépôt de l'antimoine sur le substrat étant supérieur à 10 et inférieur à 100 µg/cm².

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2. Photocathode à métal alcalin à mode de réflexion selon la revendication 1, dans laquelle au moins l'un des métaux alcalins est le sodium, le potassium, le rubidium ou le césium.

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3. Photomultiplicateur comprenant :

une photocathode à métal alcalin à mode de

Fig. 1

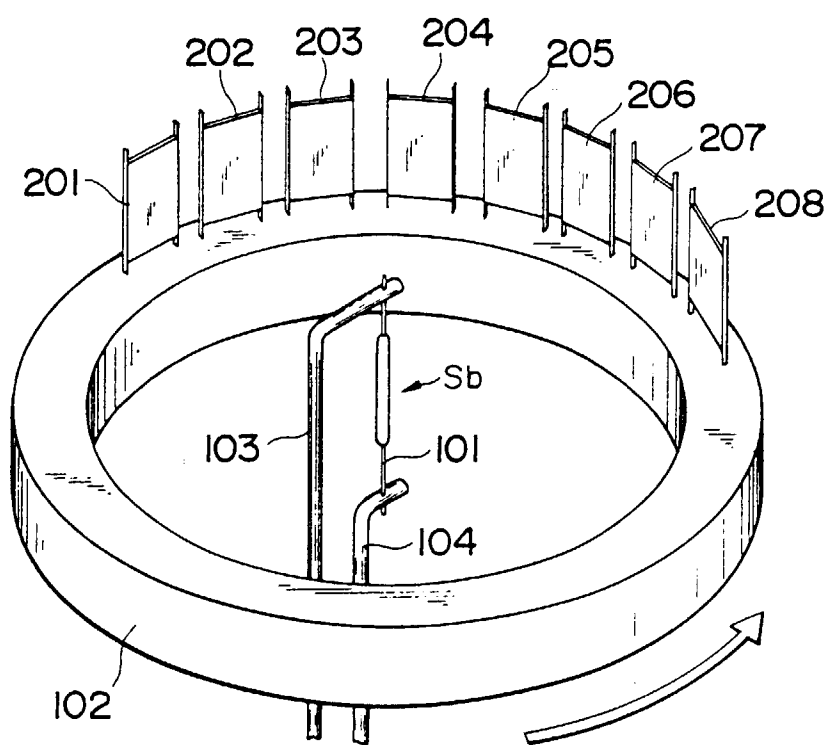


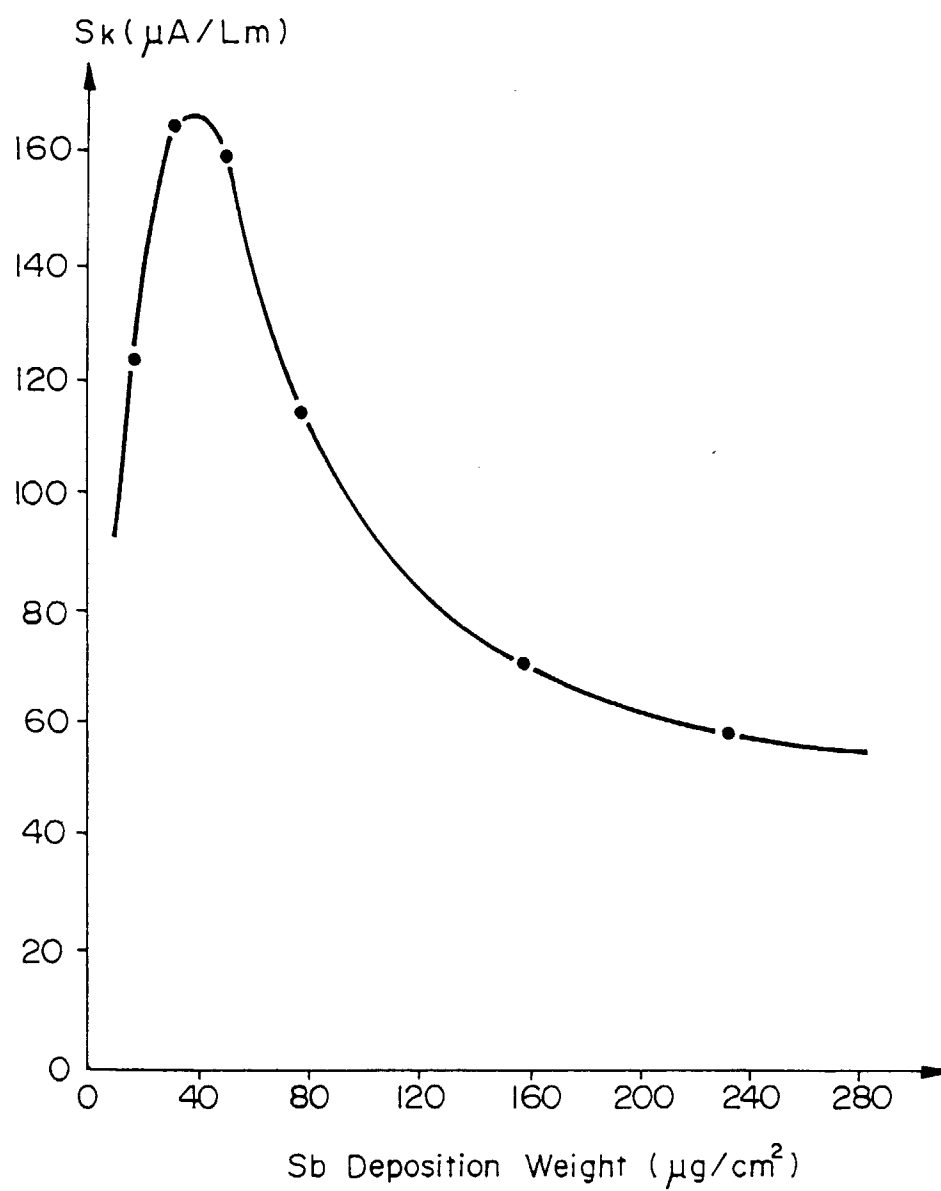
Fig.2

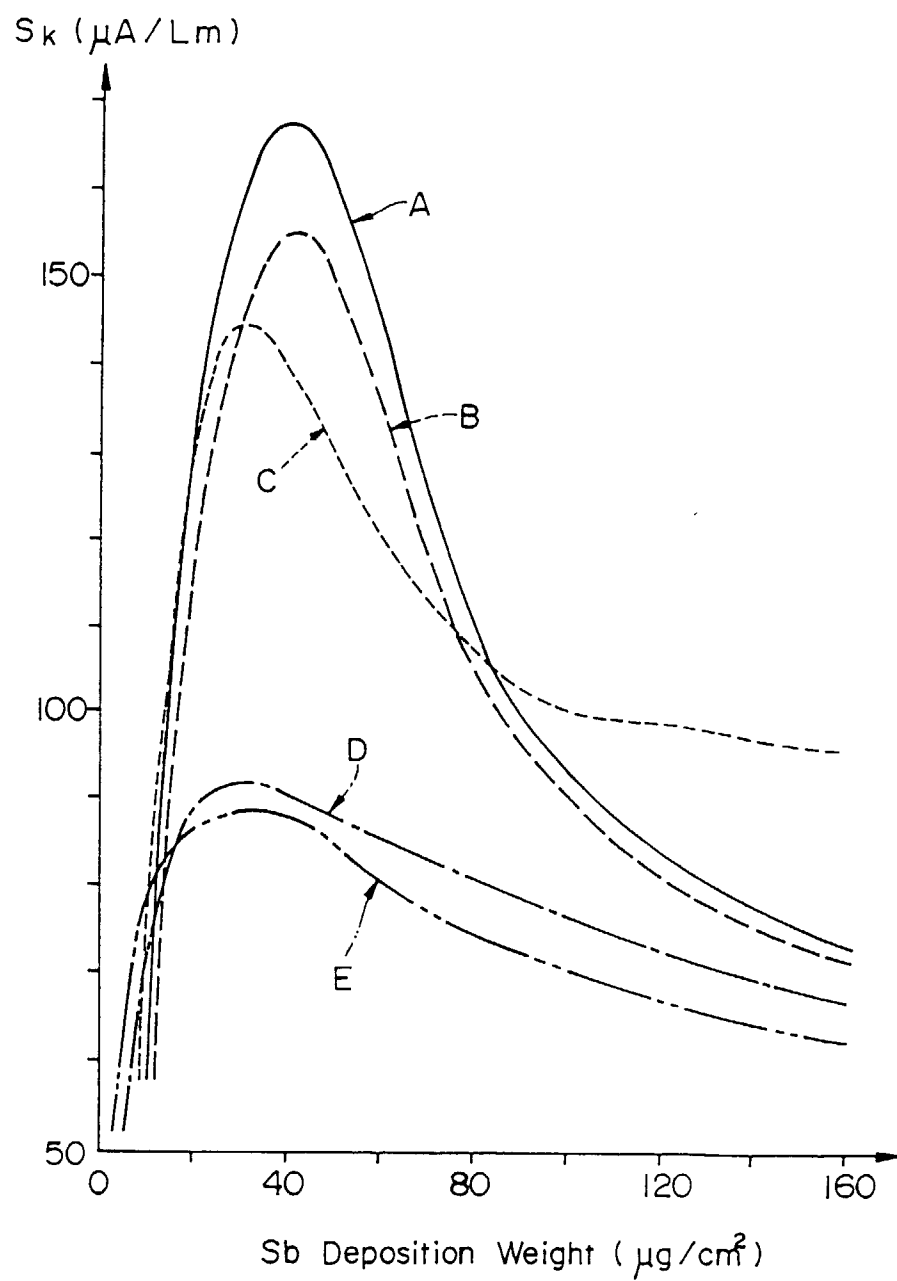
Fig. 3

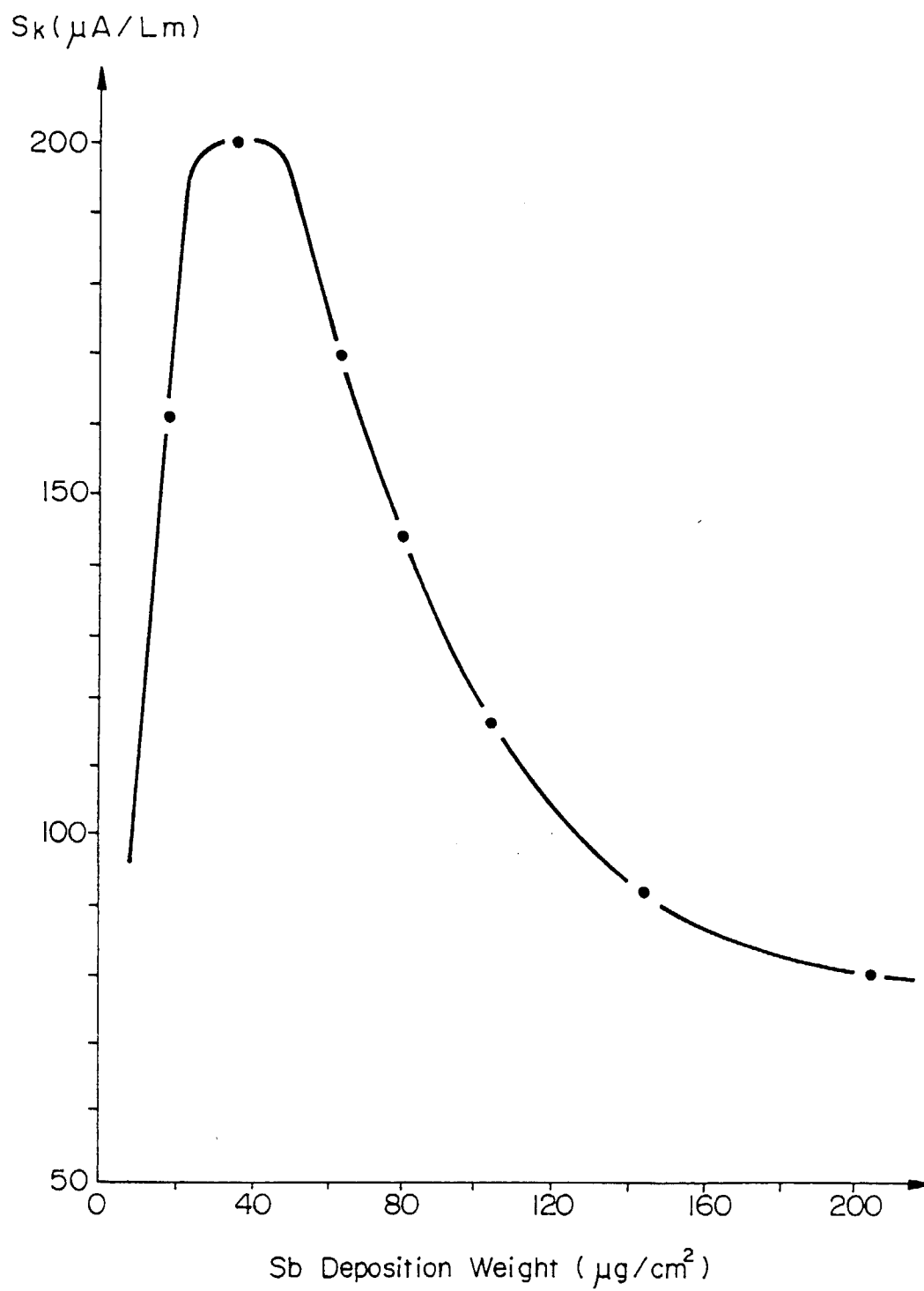
Fig. 4

Fig. 5

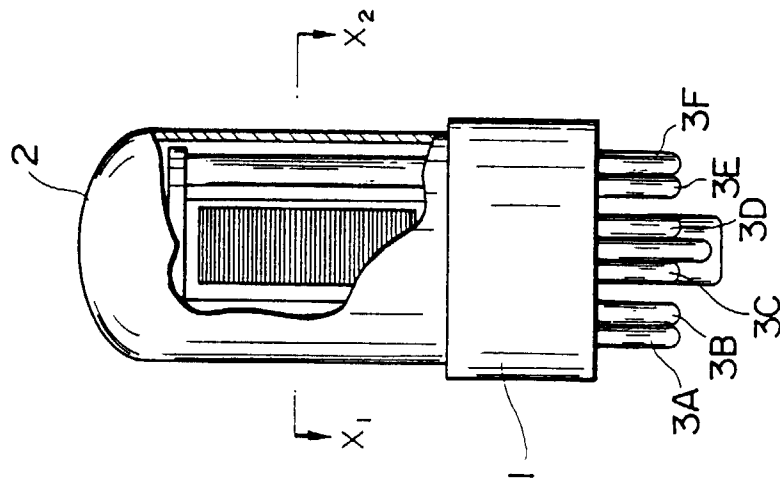


Fig. 6

