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(54) **Electrodeless high intensity discharge lamp having a boron sulfide fill**

(57) An electrodeless high intensity discharge lamp including a sealed light-transmissive lamp envelope, a volatilizable chemical fill and an inert gas or nitrogen within the envelope. The primary active component of the fill is boron sulfide. The inert gas or nitrogen within the envelope assists in starting the lamp, and is at sub-atmospheric pressure. The lamp envelope is coupled to a high frequency power source to produce a light emitting plasma discharge within the envelope.

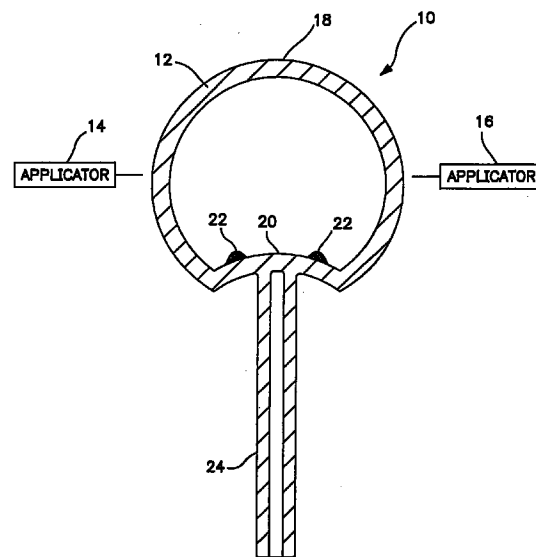


FIG. 1

EP 0 788 140 A2

Description

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application contains subject matter related to U.S. Application Serial No. [Attorney's Docket No. 92-3-336], commonly assigned and filed concurrently herewith. Application [92-3-336] is incorporated herein by reference.

BACKGROUND OF THE INVENTION

The present invention relates to electrodeless discharge light sources, and particularly to electrodeless lamps having a fill energized by high frequency, e.g., microwave power.

Until recently, all commercially available high intensity discharge (HID) lamps contained mercury or mercury salts, with other metal salts added to enhance or tailor the spectral output. Over the past several years, environmental concerns have led to attempts to produce mercury-free HID lamps. Of particular concern has been the discarding of spent lamps, releasing mercury into the environment.

One example of a mercury-free lamp which has been developed is a mercury-free high pressure sodium lamp having a fill of sodium and a high pressure (above atmospheric) of an inert gas. Some examples of sodium halide and oxyhalide lamps are described in U.S. Patents Nos. 4,672,267, 4,801,846, and 5,070,277. Like all lamps containing reactive chemical fills, these lamps are subject to wall reactions which can affect the optical properties of the arc lamp and alter the chemistry from that initial to the lamp.

In another type of mercury-free lamp sulfur, selenium, or compounds thereof are included in the lamp fill, and are excited by electromagnetic power in excess of about 50 watts/cc, preferably in excess of 100 watts/cc. Other known electrodeless lamps containing metal halides or oxyhalides have good color rendering properties and high lumen output. However, most of these also include mercury.

Accordingly, it is an object of the present invention to provide an electrodeless high intensity discharge lamp that overcomes the disadvantages of prior art lamps.

It is another object of the present invention to provide an electrodeless high intensity discharge lamp having a boron sulfide-based fill.

It is yet another object of the invention to provide an electrodeless high intensity discharge lamp having a boron sulfide-based fill which is free of mercury.

It is still another object of the invention to provide an electrodeless high intensity discharge lamp having a boron sulfide-based fill which is free of both mercury and metal halides.

It is a further object of the invention to provide a mercury-free electrodeless high intensity discharge lamp having a boron sulfide-based fill including a small

amount of a metal halide and emitting light over a broad spectral range.

These and still further objects, features, and advantages of the present invention will become apparent upon consideration of the following description.

SUMMARY OF THE INVENTION

The present invention provides an electrodeless high intensity discharge lamp having a boron sulfide-based fill which may be energized by high frequency power, e.g., microwave power supplied to the lamp to produce a light emitting plasma discharge without the need for mercury in the lamp. In some embodiments of the lamp a small amount of mercury may be included in the lamp envelope to improve resistive heating of the lamp. However, an emission may be produced in the lamp in accordance with the invention without the presence of mercury or mercury compounds.

In one embodiment, the invention is an electrodeless high intensity discharge lamp including a sealed light-transmissive envelope, a volatilizable chemical fill within the envelope, an inert gas or nitrogen within the envelope to assist in starting the lamp, and means for coupling high frequency power to the envelope to produce a light emitting plasma discharge within the envelope. The fill includes boron sulfide as a primary active component. The inert gas or nitrogen is at a pressure of less than 760 torr at ambient temperature. In a narrower embodiment, the lamp is a mercury-free electrodeless high intensity discharge lamp. In another narrower embodiment, the lamp may include as a secondary active component an amount of a metal halide, e.g., sodium iodide, lithium iodide, scandium iodide, or combinations thereof, within the envelope sufficient to augment the emission wavelength of the fill during operation of the lamp.

In another embodiment, the invention is a mercury-free electrodeless high intensity discharge lamp including a sealed light-transmissive envelope, a volatilizable chemical fill within the light-transmissive envelope, xenon gas within the light transmissive envelope to assist in starting the lamp, and means for coupling high frequency power at about 13 - 6000 MHz to the light transmissive envelope to produce a light emitting plasma discharge within the light transmissive envelope. The fill includes boron sulfide as a primary active component, the amount of the primary active component being about 1 - 10 mg for each cm³ of volume within the light transmissive envelope. The xenon gas is at a pressure of about 20 - 200 torr at ambient temperature. In a narrower embodiment, the fill further includes a secondary active component selected from sodium iodide, lithium iodide, scandium iodide, and combinations thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding of the present invention,

together with other objects, advantages, and capabilities thereof, reference is made to the following Description and appended Claims, together with the Drawing in which:

Figure 1 is a cross-sectional schematic elevation view of a spherical electrodeless high intensity discharge lamp capsule in accordance with one embodiment of the present invention;

Figure 2 is an emission spectrum for a boron sulfide fill for a lamp in accordance with another embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

An exemplary embodiment of the electrodeless HID lamp in accordance with the present invention is a mercury-free electrodeless HID lamp including a volatilizable chemical fill and an inert gas or nitrogen sealed within a light-transmissive envelope. The primary active component of the fill is boron sulfide. By the term "active component" is meant a volatilizable light emitting component, the primary active component being the component having the most predominant spectral emission. Also included in the term "active component", as used herein, are precursors of the desired active component, e.g., boron sulfide compound. The precursors are introduced to the lamp envelope to produce, e.g., the desired boron sulfide compound by chemical reaction during operation of the lamp. Thus, the light emitted by the reacted primary active component precursors is in the desired range, e.g., in the yellow to red range for a lamp fabricated with boron sulfide precursor starting materials. Optionally, sulfur or a volatilizable compound of sulfur may also be included in the fill as a secondary active component. By the term "secondary active component" is meant a radiating component which adds a spectral component where the primary active component emission is absent, to fill out or augment the spectrum and improve lumen and color properties of the lamp fill.

The boron sulfide component emits in the yellow to near infrared range of the spectrum, having a peak emission at 812 nm, and the sulfur or sulfur compound component, if present, emits in the blue to green range. Typical sulfur compound additives are indium sulfide (InS) and arsenic sulfide (As₂S₃). A small amount of a metal halide may be added to the lamp fill as a secondary active component, e.g., an amount only sufficient to augment the emission wavelength of the fill during operation of the electrodeless HID lamp. Typical metal halides include halides of sodium, e.g., sodium iodide emitting in the yellow green region, or other metal halides such as lithium iodide and indium iodide emitting in the red and blue regions, respectively. Thus the combinations of primary and secondary active components emit light over a broad spectral range. The lamp envelope is coupled to a high frequency power source to pro-

duce a light emitting plasma discharge within the envelope.

In this embodiment, no mercury or mercury compounds are introduced to the lamp envelope. In other embodiments a small amount of mercury may be added to improve resistive heating of the lamp, typically about 1 - 35 mg/cm³ of volume of the light transmissive envelope. However, the presence of mercury or mercury compounds is not required to produce an emission in the lamps described herein.

The inert gas or nitrogen mentioned above is present within the envelope at subatmospheric pressure (less than 760 torr at ambient temperature) to facilitate starting of the lamp, i.e., establishing the light emitting plasma discharge within the envelope. These gases may be any of the Group VIII inert gas elements, nitrogen, or a combination of these. The preferred inert gas is argon, krypton, or xenon; most preferred is xenon. The preferred pressure for the inert gas is about 1 - 700 torr, more preferred is about 20 - 700 torr, most preferred is about 20 - 200 torr. At 20 - 200 torr, the inert gas is readily ionized by the available high frequency power, and rapidly transits to a thermal arc. At lower pressure the inert gas is easier to ionize, but transition to the thermal arc is slower and the lamp requires a longer warm-up time. At higher pressure the inert gas is more difficult to ionize, requiring a higher power application to establish the thermal arc.

The amount of volatilizable active fill components within the envelope depends on the volume of the envelope. Preferably, an excess of the active components is present within the envelope, i.e., a sufficient amount for the lamp to operate in saturated mode with condensate present at operating temperature. If an excess of the active components is present the fill amount is not critical. The preferred amount is about 1 - 100 mg per cm³ of envelope volume; most preferred, about 1 - 10 mg/cm³. Alternatively, the lamp may be operated in unsaturated mode, with no condensate present at operating temperature. However, for operation in the unsaturated mode, the fill amount must be selected more precisely. The amount of fill in the unsaturated mode is preferably 0.1 - 1 mg/cm³.

As mentioned above, the lamp envelope is coupled to a high frequency power source to produce a light emitting plasma discharge. Preferably, the lamp is powered by a high frequency RF source operating at about 13 - 6000 MHz. More preferably, the power source operates within the ISM bands (Industrial, Scientific and Medical bands, established by the Federal Communications Commission) throughout that region of the electromagnetic spectrum, most preferably in the ISM bands centered around 915 and 2450 MHz.

The discharge is initiated in the inert gas, which then heats and volatilizes the chemical fill, increasing the vapor pressure within the envelope. The active component or components then begin to dissociate and ionize, emitting within the spectral ranges mentioned above. The plasma arc temperature is influenced by the

vapor pressure within the envelope and the power applied thereto. The arc temperature, in turn, influences the distribution of population in the excited molecular electronic state. Thus, the wavelength of the maximum emission may be shifted slightly by varying the power applied to the envelope. Further, the high operating pressure of the vaporized active component(s) provides thermal insulation to isolate the core of the discharge, raising the arc core temperature and permitting population of the higher vibrational levels of the excited state(s) of the active component(s).

The preferred high frequency power source for the lamps disclosed herein is a microwave power source. Most preferred is a microwave power source including a plurality of electric field applicators spaced around the envelope. A power splitter and phase shifter cause the electric field applied to the envelope by the applicators to rotate at the frequency of the power source. Such a power source is disclosed in U.S. Patent Application Serial No. 08/248,921 filed May 24, 1994, incorporated herein by reference. Alternatively, another type of high frequency power source may be utilized, e.g., that disclosed in above-referenced Patent 5,070,277 or other known high frequency applicators. Preferably, the applicator used should permit the lamp to be small with a well concentrated high frequency powered plasma. The entire applicator preferably is mountable within an optical device which is optimizable for collection of the emitted light independently of the microwave power source.

The lamp capsule, or light transmissive envelope, is fabricated from vitreous silica (commonly called quartz), synthetic silica, hard glass, ceramic (e.g., polycrystalline alumina or yttria), or a single crystalline material such as a crystalline alumina (sapphire). The lamp capsule also may be fabricated from a broad range of other materials, including lower temperature glasses than are usable with prior art electrodeless HID lamps. The lower temperature glasses are permitted because the volatilizable primary active material vaporizes at a lower temperature than prior art primary active materials, and is less chemically reactive with the glass than the metal salts used in conventional HID lamps.

The description below of various illustrative embodiments shown in the Drawing refers to a spherical medium-powered lamp. However, it is not intended to limit the scope of the present invention, but merely to be illustrative and representative thereof.

Referring now to Figure 1, electrodeless HID lamp 10 in accordance with one embodiment of the present invention includes spherical electrodeless lamp capsule 12, described in more detail below, and electric field applicators 14 and 16 on either side of and in close proximity to lamp capsule 12. Applicators 14 and 16 are used for nonresonant coupling of high frequency electromagnetic power to lamp capsule 12. In a preferred alternative arrangement, applicators 14 and 16 are two of four electric field applicators of the system described in above-referenced Application 08/248,921. The electric field applicators are preferably helical couplers or

helical coils. The electric field applicators are spaced around lamp capsule 12 in a plane intersecting the center of the lamp capsule and spaced at 90° intervals with respect to the lamp capsule center. A high frequency power source (not shown) supplies high frequency power to a power splitter (not shown) and phase shifter (not shown) such that the electric field applied to lamp capsule 12 by the four applicators rotates at the frequency of the power source. In another alternative arrangement, not shown, a pair of applicators may be located above and below lamp envelope 18, aligned with its axis of rotation (not shown).

Envelope 18 of lamp capsule 12 is fabricated of a light transmissive material through which the high frequency power passes substantially unattenuated. The material of lamp envelope 18 may be quartz, synthetic silica, hard glass, ceramic, or a single crystalline material such as sapphire. Lamp envelope 18 is shown in Figure 1 as spherical, but may be of any shape conventional for electrodeless lamp capsules, e.g., generally prolate or oblate ellipsoidal in cross section, e.g., a cross section normal to the plane of excitation. Preferably, lamp envelope 18 has an approximately circular cross section in the plane of excitation. The inner diameter of lamp capsule 18 is preferably about 1 - 12 mm, more preferably 2 - 8 mm. The wall thickness may be, e.g., about 0.25 - 2.0 mm. For operation in the saturated mode, lamp envelope 18 may have one or more dimples, as dimple 20, extending into its interior volume to assist in controlling distribution of fill condensate 22. Condensate 22 forms a ring around dimple 20. Support rod 24, which may be tubular as shown or solid and is preferably aligned with the center of lamp envelope 18, supports lamp envelope 18. A second support (not shown) may be positioned diametrically opposite rod 24 and co-linear therewith. Lamp envelope 18 contains an ionizable inert gas or nitrogen, preferably xenon, at about 20 - 200 torr at ambient temperature. Lamp envelope 18 also contains, as the primary active component of the fill, a vaporizable fill material made up of boron oxide (B_2O_3) and sulfur (S_2) which, when heated, react to form boron sulfide (B_2S_3), as described above. Alternatively, boron metal and diatomic sulfur may be used as the starting materials, or purified B_2S_3 may be introduced directly to the lamp. This boron sulfide primary active component, when volatilized, is partially ionized and partially excited to radiating states so that useful light is emitted by the discharge.

In operation, the power source is activated, establishing an electric field at the center of the lamp envelope and ionizing the inert gas or nitrogen component. The molecules of the active component(s) vaporize, diffuse into and, if present as compounds, dissociate in the arc, producing light.

The following Example is presented to enable those skilled in the art to more clearly understand and practice the present invention. These Examples should not be considered as a limitation upon the scope of the present invention, but merely as being illustrative and represent-

ative thereof.

EXAMPLE

A 60 W electrodeless HID lamp was prepared by filling a standard tubular electrodeless HID lamp capsule, 3 mm ID, 5 mm OD, 10 mm internal length, with a boron sulfide fill formed in situ (added as boron oxide and S₂). No mercury was added to the lamp capsule. The emission spectrum of the lamp fill is shown in Figure 2, showing a peak emission at 812 nm, with additional peaks arising from the krypton inert fill gas.

The lamp capsule was sealed and mounted within a high frequency RF source to provide high frequency power to the lamp at 915 MHz. The lamp operated in unsaturated mode, providing 400 lumens of light. The correlated color temperature of the lamp was 3295 K; the general color rendering index was not measured.

The invention described herein presents to the art novel, improved electrodeless HID lamp having a boron sulfide fill. The lamp requires no mercury or mercury salts and no substantial amount of metal halides to produce useful light. The boron sulfide fill emits in the yellow to red range of the visible spectrum and, if the additives described above are included in the fill, the emission may be shifted or broadened to include the yellow-green, blue, or ultraviolet ranges of the spectrum.

While there has been shown and described what are at present considered the preferred embodiments of the invention, it will be apparent to those skilled in the art that modifications and changes can be made therein without departing from the scope of the present invention as defined by the appended Claims.

Claims

1. An electrodeless high intensity discharge lamp comprising:

a sealed light-transmissive envelope;
 a volatilizable chemical fill within said envelope, said fill including boron sulfide as a primary active component;
 an inert gas or nitrogen within said envelope to assist in starting said lamp, said inert gas or nitrogen being at a pressure of less than 760 torr at ambient temperature; and
 means for coupling high frequency power to said envelope to produce a light emitting plasma discharge within said envelope.

2. A lamp in accordance with claim 1 wherein said lamp is a mercury-free electrodeless high intensity discharge lamp.

3. A lamp in accordance with claim 2 wherein said lamp is free of both mercury and metal halides.

4. A lamp in accordance with claim 1 further compris-

ing as a secondary active component an amount of a metal halide within said envelope sufficient to augment the emission wavelength of said fill during operation of said lamp.

5. A lamp in accordance with claim 4 wherein said metal halide is selected from the group consisting of sodium iodide, lithium iodide, scandium iodide, and combinations thereof.

6. A lamp in accordance with claim 1 wherein the amount of said primary active component is sufficient for condensate of said primary active component to be present in said envelope during operation of said lamp.

7. A lamp in accordance with claim 1 wherein the amount of said primary active component is about 1 - 100 mg for each cm³ of volume within said envelope.

8. A lamp in accordance with claim 7 wherein the amount of said primary active component is about 1 - 10 mg for each cm³ of volume within said envelope.

9. A lamp in accordance with claim 1 wherein said inert gas or nitrogen is at a pressure of about 20 - 700 torr at ambient temperature.

10. A lamp in accordance with claim 9 wherein said inert gas or nitrogen is at a pressure of about 20 - 200 torr at ambient temperature.

11. A lamp in accordance with claim 9 wherein said inert gas or nitrogen is nitrogen, xenon, krypton, or argon.

12. A lamp in accordance with claim 1 wherein said means applies said high frequency power at about 13 - 6000 MHz.

13. A lamp in accordance with claim 1 wherein said light-transmissive envelope is fabricated from a light transmissive material selected from the group consisting of vitreous silica, synthetic silica, glass, sapphire, and ceramic.

14. A mercury-free electrodeless high intensity discharge lamp comprising:

a sealed light-transmissive envelope;
 a volatilizable chemical fill within said light-transmissive envelope, said fill including boron sulfide as a primary active component, the amount of said primary active component being about 1 - 10 mg for each cm³ of volume within said light transmissive envelope;
 xenon gas within said light transmissive enve-

lope to assist in starting said lamp, said xenon gas being at a pressure of about 20 - 200 torr at ambient temperature;

means for coupling high frequency power at about 13 - 6000 MHz to said light transmissive envelope to produce a light emitting plasma discharge within said light transmissive envelope.

15. A lamp in accordance with claim 14 wherein the amount of said primary active component is sufficient for condensate of said primary active component to be present in said envelope during operation of said lamp.

16. A lamp in accordance with claim 14 wherein said fill further comprises a secondary active component selected from the group consisting of sodium iodide, lithium iodide, scandium iodide, and combinations thereof.

17. A lamp in accordance with claim 14 wherein said lamp is free of both mercury and metal halides.

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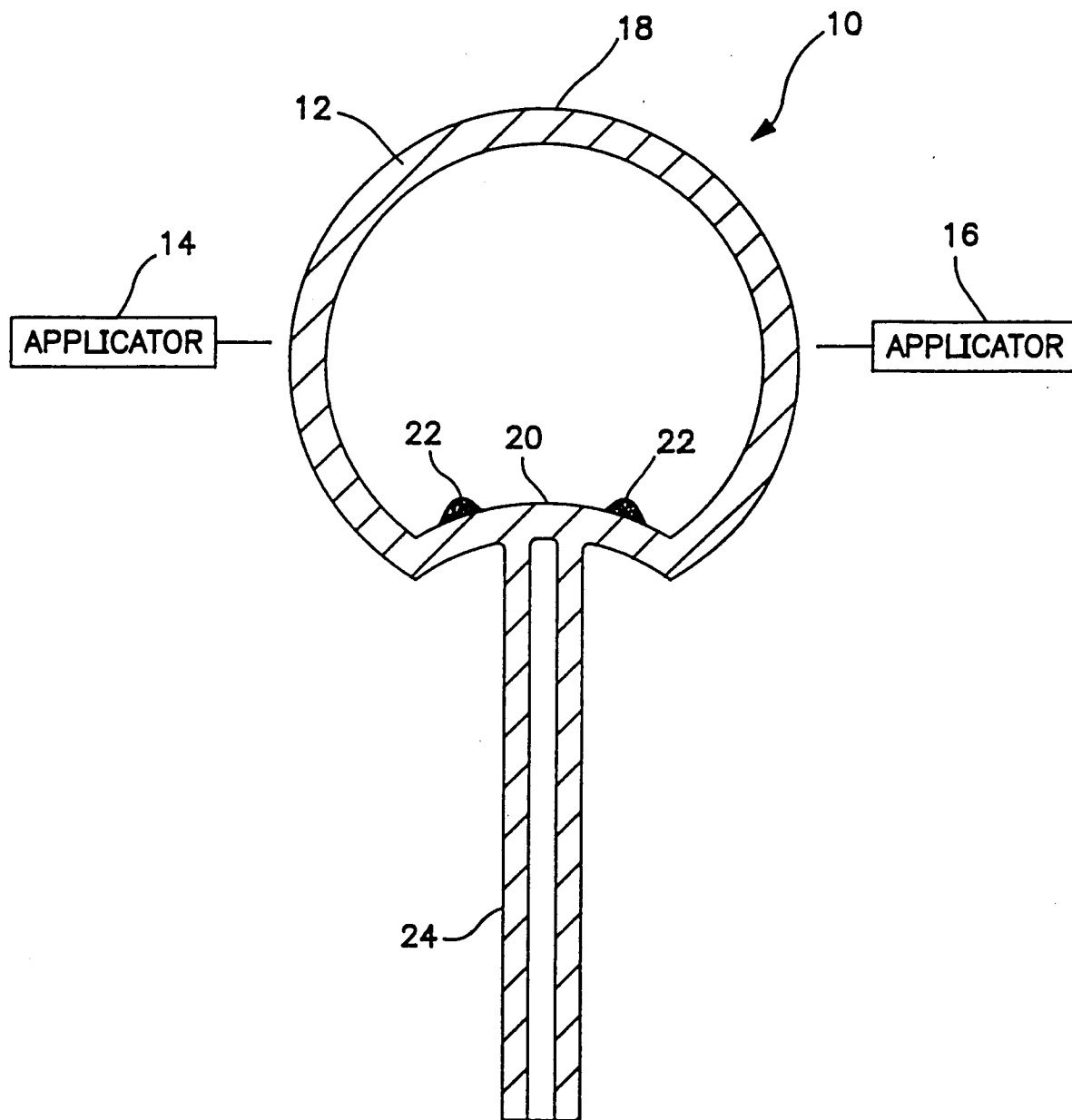


FIG. 1

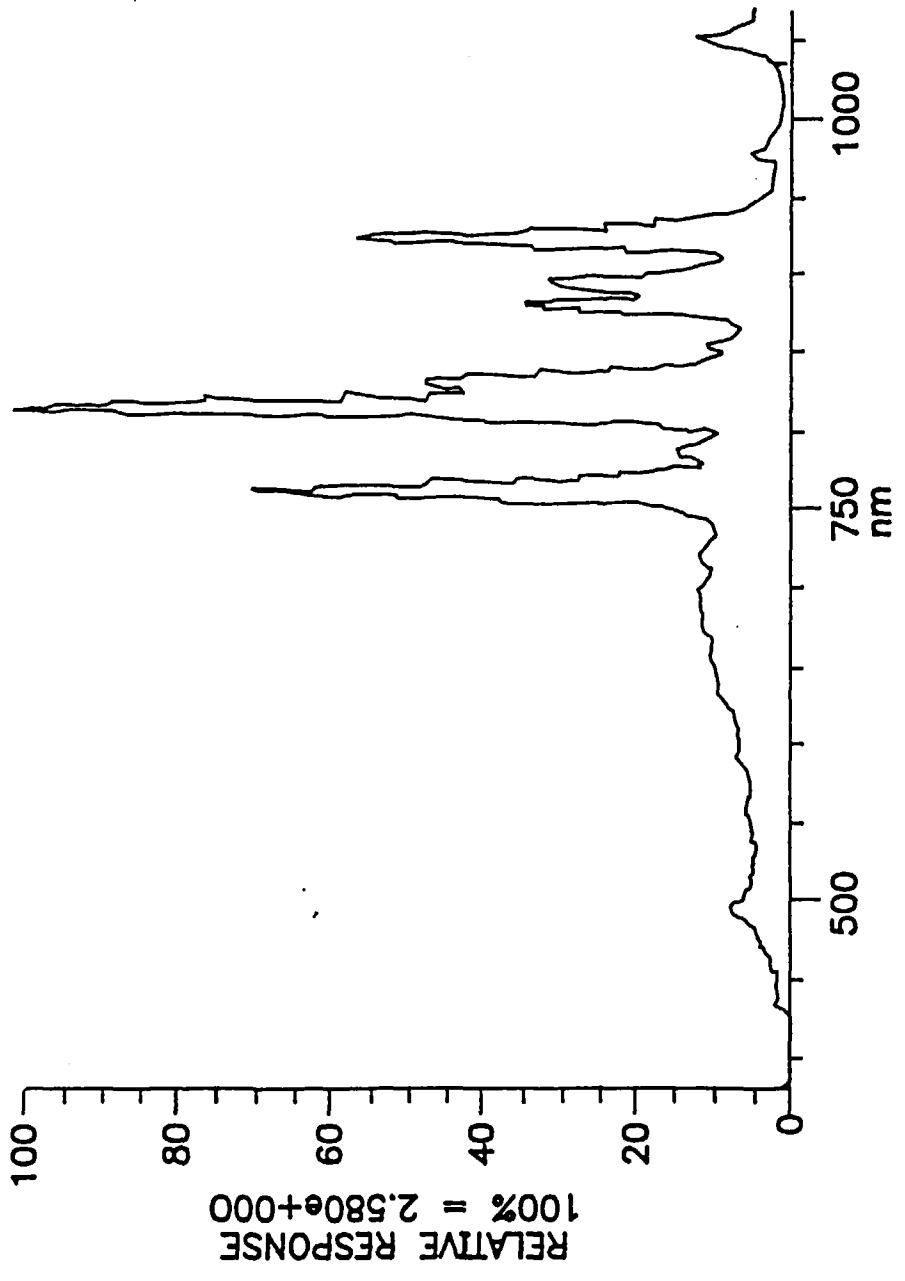


FIG. 2