(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 080 820**
A2

(12) # EUROPEAN PATENT APPLICATION

(21) Application number: 82306041.3

(22) Date of filing: 12.11.82

(51) Int. Cl.³: H 01 J 61/28
H 01 J 61/02

(30) Priority: 27.11.81 GB 8135910

(43) Date of publication of application: 08.06.83 Bulletin 83/23

(84) Designated Contracting States: DE FR GB NL

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(54) **Improvements in or relating to discharge lamps.**

(57) In high pressure discharge lamps, for example, high pressure sodium lamps improved colour, closer to white, has been sought, for example by the use of external heat shields to raise the temperature of the dose amalgam.

The present invention introduces a wick (18) disposed around the shank (2) of one electrode. Made of a material which is wetted by the liquid dose in use it acts, if the lamp is appropriately orientated, to move the dose (8) by surface tension to a hotter part of the lamp. Effective control of vapour pressure and therefore lamp colour can be obtained by suitable tailoring of the wick dimensions or materials or both.

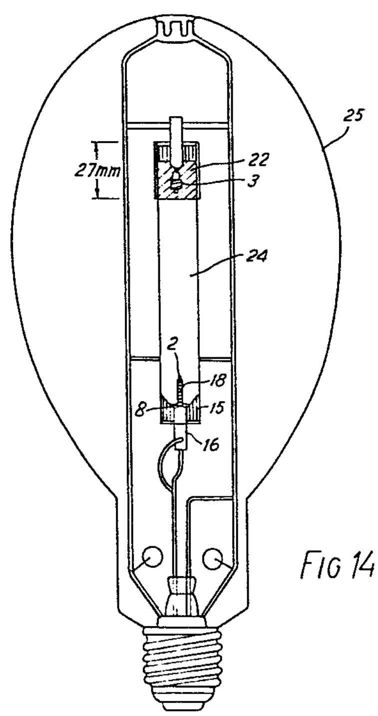

FIG 14

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IMPROVEMENTS IN OR RELATING TO DISCHARGE LAMPS

The present invention relates to discharge lamps and is particularly, although not exclusively, related to high pressure discharge lamps such as high pressure sodium lamps and mercury lamps.

Discharge lamps comprise a sealed discharge or arc tube of a light transmitting material having electrodes at opposite ends and containing a fill comprising a dose of substances which emit light when a discharge is struck between the electrodes. The dose may comprise: mercury; mercury with the addition of metal halides to improve the spectrum of the light emitted; a sodium/mercury amalgam in the case of high pressure sodium lamps or other more complex mixtures. The fill also includes an inert gas to act as a starter for the discharge.

Much work has been done on discharge lamps to improve their luminous efficacy and colour rendering and improvements have been achieved in part by developments in the doses used.

It is an object of this invention to provide an alternative form of discharge lamp.

According to one aspect of the present invention there is provided a high pressure discharge lamp including a light transmitting arc tube having, sealed into the ends thereof, electrodes each comprising at least an electrode shank and within the arc tube a dose suitable to be liquid at least in part at the working temperature of the lamp, the lamp further including a reservoir region adapted to collect the liquid dose when the lamp is appropriately orientated and transfer means arranged to be in contact with the liquid dose when the lamp is appropriately orientated and constructed so that, in operation, at least part of the liquid dose is moved to a hotter part of the tube by the action of surface tension.

According to another aspect of the present invention there is provided a high pressure discharge lamp including: a light-transmitting arc tube; two electrodes, each comprising at least an electrode shank sealed into opposing ends of the arc tube; within the arc tube a dose suitable to be liquid at least in part when the lamp is in operation; and transfer means disposed in the region of at least one of said electrode shanks and made of a material which will be wetted by the liquid dose at the operating temperature of the lamp so that in operation, with the lamp appropriately orientated, the transfer member is capable of moving some of the liquid dose to a hotter part of the lamp by the action of surface tension.

In order that the invention may be clearly understood and readily carried into effect it will now be described by way of example with reference to the accompanying drawings, of which:

Figure 1 shows a discharge tube incorporating an example of the invention,

Figure 2 illustrates the result of operating the tube of Figure 1 in one orientation,

Figure 3 illustrate the results of operating the tube of Figure 1 in the inverse orientation to Figure 2,

Figure 4 illustrates an adaptation of the tube of Figure 1 incorporating a silica sleeve,

Figure 5 illustrates the tube of Figure 4 in a complete discharge lamp,

Figure 5a shows an alternative lamp to that of Figure 5 with two starter electrodes,

Figure 6 shows an alternative discharge tube for horizontal burning,

Figure 7 shows one end arrangement of the invention suitable for an alumina discharge tube,

Figure 8 shows an alternative to Figure 7,

Figure 9 shows another alternative to Figure 7,

Figure 10 shows a wick braid wound on a conventional electrode shank,

Figure 11 shows an alternative to Figure 10,

Figure 12 illustrates the sealing of an electrode as in Figure 10 in a fused silica discharge tube.

Figure 13 shows a wick made from a conventional SON electrode primary coil,

Figure 14 shows one example of a lamp incorporating the invention,

Figure 15a and 15b show spectra for the lamp of Figure 13 operated in different manners,

Figure 16 illustrates the relationship between lamp voltage and wick length for a lamp incorporating the invention, and

Figure 17 shows a porous cermet wick.

Recently interest has developed in the heat pipe as a heat transfer device, for example as described in British Patent No. 1 027 719. The device comprises a sealed container with a condensable vapour therein. Capillary means transports the condensed vapour from a cooler region to a hotter region where it evaporates to be transferred to the cooler region by the vapour pressure gradient and there to condense. Thus a heat transfer cycle is set up.

The heat pipe shows that surface tension can be used to move liquids to regions of higher temperature, even against the force of gravity, and it is now proposed to use heat pipe technology in a new form of discharge lamp.

In discharge lamps the electrodes generally comprise a metal, usually tungsten, electrode shank often overwound with a coil which may be impregnated with electron emitter.

It is proposed to add to such an electrode, with or without the overwound coil, a transfer member which may transport a working fluid component of the fill, if in contact with a liquid reservoir thereof. This member, which in the broadest sense may be considered to be porous, will for the purposes of this specification be called a "wick". A particularly convenient form of wick for this purpose is a braid of tungsten wire wrapped around the electrode shank.

To illustrate one embodiment of the invention Figure 1 shows a fused silica discharge tube 1, in this example of a type used in a 1000 watt mercury metal halide lamp, and having an internal volume of about $30cm^3$. A conventional electrode at one end comprises a tungsten shank 2, which may optionally contain a small proportion of thorium, with a tungsten coil overwind 3. Electrical connection to the electrode is through a molybdenum foil 4 in a conventional pinch seal 5. At the other end the electrode comprises a tungsten shank 6 surrounded by a tungsten wick 7. Electrical connection is also by a molybdenum foil 4 in a pinch seal 5. In this example the wick 7 extends down the shank 6 to the pinch and if the tube is operated vertically as shown in Figure 1 a liquid reservoir 8 of the dose forms.

In operation there is a large temperature gradient (500-1500°C) along the length of the wick 7. Surface tension lifts the liquid dose, against gravity and the temperature gradient, and the dose evaporates to increase the vapour pressure in the lamp. The dose subsequently returns to the reservoir 8 under gravity and a true heat pipe results.

It is an important consideration that the liquid dose should 'wet' the wick, to be properly transported, and for the present purposes wetting may be defined as the achievement of a wetting angle θ defined by $0^\circ \leqslant 0 < 90^\circ$.

It is thought that any metal will wet tungsten in the absence of oxide layers and in these circumstances the addition to the dose of metals such as Calcium and Barium, having a great affinity for oxygen, promotes wetting (See Addison et al, J. Chem. Soc.(1962) 2699-2705).

In general it is considered that a wick should be a material which will be wetted by a metal or metal compound dose at a temperature above the melting point $x^{\circ}C$ of the dose. For silica arc tubes the temperature x should preferably be lower than $1000^{\circ}C$ and for polycrystalline alumina arc tubes the temperature x should preferably be lower than $1100^{\circ}C$.

The wick 7 may take different forms suitable to transport the liquid dose by surface tension. It is considered that a wick of pore radius of about 0.1mm would suit a worst case of a liquid with the density of mercury.

A convenient form is a braided tungsten wire which is used as an electrode overwind in some forms of high pressure mercury fluorescent lamps. It is difficult to wind a braid directly on the electrode shank 6 as mandrel because of difficulties in cutting the ends and with the braid springing away from the mandrel. Moreover, multiple layers of braid are desirable. The braid may however be wound in conventional manner on a molybdenum wire as mandrel, the mandrel being dissolved out and the braid fitted on to the electrode shank as a coiled coil. Alternatively, the molybdenum primary mandrel may be replaced by tungsten wire which is left in situ to strengthen the braid and reduce the pore size.

Considering two experimental lamps which have been made in this way, one (A) had an open braid overwind with holes of about 0.11mm diameter and the other (B) had a braid retaining a tungsten primary mandrel and thus much smaller holes. Both of these experimental lamps had a conventional electrode at the other end, as used for mercury-metal halide lamps. The braided overwinds were approximately 5mm long (double the length of a normal overwind) in order to extend to the pinch. The dose halide chosen was sodium iodide because of its suitable characteristics (melting point $651^{\circ}C$, boiling point $1300^{\circ}C$) and also because the distribution of sodium in the arc can be observed visually. Sodium iodide is known as a dose in metal halide lamps but in such lamps the partial pressure of sodium is low because of the low vapour pressure of sodium iodide. For this invention each tube was dosed with 3.67mg cm^{-3} of mercury and 3.0mg cm^{-3} anhydrous sodium iodide and 15 torr cold fill pressure of argon as a starter gas. This relatively high dose of sodium iodide was in part chosen to ensure the formation of a liquid pool.

The tubes were operated vertically at 1000 watts.

In one experiment both tubes A and B were operated with the conventional electrode at the bottom and ran stably as normal NaI-Hg arcs, as illustrated in Figure 2 which applies to both lamps. As shown in Figure 2 the glow divided into two parts visibly different as indicated by different directions of hatching. The part 9 is the orange sodium glow which is extensive because of the large dose of sodium iodide. Shown at 10 is a blue part of the glow dominated by mercury radiation. The condensing dose is shown at 11.

The lamps were also run with the wick electrode at the bottom and the conventional electrode at the top. In these circumstances the arc behaved quite differently. At intervals of about forty seconds the arc became constricted and swirled around the tube for a period of about five seconds. The instability for lamp A is then illustrated in Figure 3.

With the wick at the bottom, the orange colour of the sodium glow was deeper (indicating a higher partial pressure of sodium), the arc voltage at rated watts fell by 10-15 volts and the luminous efficacy increased. With lamp B, for example, it is possible to increase the efficacy from 90 lm W^{-1} (with the wick at the top) to 119 lm W^{-1}. The intermittent instability is thought to be caused by the delay while condensed droplets of dose coagulate before falling under gravity to the base of the wick.

The capillary action can be made continuous by moving the cool spot nearer to the base of the wick. One means of achieving this which may be used in some production lamps is to provide a close fitting silica sleeve around all but the bottom

5 to 20mm (but preferably the bottom 10mm) of the tube. This is illustrated in Figure 4 in which a 30mm diameter silica tube 11 is fitted around the arc tube 1. Such a tube should have an internal diameter such that a gap between 3 and 10mm (but preferably about 4mm) separates it from the arc tube on all sides. With tube 11 in place and the wick at the bottom a lamp such as A or B can be operated with a colour appearance similar to a high pressure sodium lamp.

Figure 5 shows such a lamp, based on the arc tube 1 of a 1000 watt mercury-metal halide lamp and with the outer silica tube 11, mounted in a conventional glass outer envelope 12. It is supported in the manner of a metal halide lamp by a metal framework and electrical connections in the conventional manner to an end cap in this example a "Goliath Edison screw" (GES) cap 13. This lamp may be started by a high frequency pulse applied externally to the arc tube. Other known forms of starting may be used as desired. For example Figure 5A shows a 1000W lamp similar to that of Figure 5 but having starting electrodes at both ends. This lamp is about 400mm long overall with a 90-95mm arc gap. It should be noted that the sodium iodide vapour pressure given by the dose described hereinbefore is too great for a practical lamp, as evidenced by the instability which is typical of metal halide lamps with excessive halide vapour pressure and it is envisaged that the lamp of Figure 5 should have between one tenth and one half of that sodium iodide vapour pressure. The vapour pressure can be reduced by employing the invention to a more limited extent : for example, by shortening the wick or using a larger effective pore radius.

It will be appreciated by those skilled in the art that the principles of the invention may be extended to other lamps. For example mercury-metal halide lamps may be dosed with other halides, such as rare earth halides, which liquefy at typical arc tube temperatures but which have low vapour pressures.

The invention may be used with high pressure sodium lamps, enhancing the vapour pressure of other metals to modify the colour. The invention is particularly advantageous for metal vapour lamps such as high pressure sodium since it is especially desirable to increase the vapour pressure of metals or their alloys to improve colour while many metal halides (as used in mercury-metal halide lamps of the prior art) have sufficiently high vapour pressures at the operating temperatures of arc tube envelopes.The sodium may also be omitted, to give new types of high pressure metal vapour-mercury lamps. It should be noted that mercury is notoriously reluctant to wet wicks but better wetting of metal wicks can be obtained with amalgams than with pure mercury.

The invention may be used with horizontal burning lamps with suitable wick design. This may be with a metallic or insulating wick along the tube wall or may be with a tube design as shown in Figure 6 in which the tube has the conventional electrodes at the ends and in the wall a depression 14 which may hold a reservoir of liquid 8 when it is at the bottom. A wick 7 is placed in this depression to provide the required heat pipe action.

A number of other arrangements for the wick electrode may be adopted, of which some are illustrated in Figures 7-12.

Figure 7 shows a preferred arrangement for a polycrystalline alumina discharge tube 1 having an end plug 15, which is also of polycrystalline alumina. Inset therein is a niobium tube 16 supporting an electrode shank 2 with a tungsten braid 18 serving both as overwind and as wick. The end of the braid 18 nearest to the electrode top may optionally be impregnated with an electron emissive substance. In this example the end plug 15 is shaped to be concave and the niobium tube 16 is also positioned so as to provide a reservoir for the liquid dose 8. Gravitational forces thus assist in the creation of a liquid pool at the base of the wick.

Figure 8 shows a similar arrangement except that the end plug 19 is made of a ceramic-metal (cermet). Where, as in Figure 8 the cermet is electrically conducting, the tungsten shank of the electrode need not pass completely through the plug 19. A metal wire 17, preferably of doped molybdenum, is sintered into the exterior side of the plug, for electrical connection.

Figure 9 shows a further alternative for an alumina arc tube in which the electrode shank 2 carries a braid wick 18 similar to those of Figures 7 and 8. In this example the electrode 2 is sintered into the boss of a conducting cermet end plug 20, which is sealed by a glass frit 21 to the polycrystalline alumina plug 15. The lead wire 17 is preferably of molybdenum and can be brazed or, preferably, sintered into cap 20. For sintering it is preferable to use doped molybdenum which is more ductile.

Looking at one form of the electrode itself in more detail, Figure 10 shows how a wick in the form of a tungsten braid 18 may be fitted around an electrode shank 2 so that it might, when sealed into, for example, a fused silica tube, contact the reservoir of liquid dose. With polycrystalline alumina discharge tubes, using niobium tubes as electrical lead-throughs, it is preferred to weld the shank 2 to the niobium tube 16 before fitting the wick. In this example a conventional electrode overwind 3 is used. This comprises a primary coil overwound with a secondary coil.

In Figure 11 is an alternative as used in Figure 7 in which the braid 18 extends over a longer part of the shank 2, without a separate conventional overwind.

Figure 12 shows the manner in which an electrode as in Figure 10 may be sealed into a fused silica tube 1 so that the wick braid 18 meets the pinch seal 5. In this manner it extends to the very lowest point and will be immersed in any liquid dose which collects there. The pinch seal preferably has a smaller radius of curvature near the base of the wick.

In a construction such as that of Figure 10, either for use in an alumina arc tube or a fused silica arc tube as shown in Figure 12, the primary (inner) coil of a conventional lamp electrode overwind may be used as a wick. A suitable coil is the primary coil of a 400 watt SON (high pressure sodium) lamp. An example of a coil wick of this form is shown at 26 in Figure 13, mounted on a shank 2 supported on a niobium tube in the manner of Figure 7.

By way of a specific example of the effectiveness of the invention, Figure 14 shows (but not to scale) a lamp in which a polycrystalline alumina arc tube 24, 113mm long and 7.4mm internal diameter, a size commonly used for 400W high pressure sodium lamps, is mounted inside an evacuated elliptical outer glass bulb 25. The lower end of the arc tube has a braided wick on the electrode and concave plug, both of the type described with reference to Figure 7. The upper end has a conventional electrode 3 and shape of plug commonly used in high pressure sodium lamps.

The lamp is dosed with about 40mg sodium and 160mg mercury in the form of an amalgam with 15 torr xenon cold fill pressure. In order to ensure that the bottom of the arc tube is the region in which the dose liquefies a cap 22 of niobium metal was placed around the top.

For testing purposes two such lamps were operated at 400W one with the wick electrode at the bottom and the other with the standard electrode at the bottom. With the standard electrode at the bottom the lamp ran at 104V, 4.4A and produced the spectrum of Figure 15a which is essentially that of a prior art high pressure sodium lamp, with a golden yellow colour. The lamp run with the wick electrode at the bottom had a white colour with the spectrum of Figure 15b and ran at 385V, 1.3A. This indicates a much higher partial pressure of sodium in the lamp. Both lamps operated stably.

In another example lamps generally similar to that of Figure 14 have been made, having at one end braided tungsten wicks of various lengths (3mm, 5mm and 7mm) on electrodes with conventional overwinds in the manner of Figure 10.

Figure 16 is a graph of the potential difference across the lamp at a constant power of 400 watts as a function of wick braid length, the partial pressure of sodium being strongly correlated with the potential difference.

It can be seen from Figure 16 that variation of the wick length provides an effective control of vapour pressure (and hence of colour). High pressure sodium lamps of improved colour and higher sodium vapour pressure have been produced in the prior art by the use of external heat shields, so that not only the dose amalgam but also the components of the end seal are subject to much higher temperature, thus increasing the chemical reaction rate between, for example, the dose amalgam and the sealing glass. With the present invention an external shield is not necessary at the end containing the liquid amalgam and the end seal is therefore cooler. Chemical reaction rates are therefore thought to be less for a given lamp performance than with prior art lamps.

Other mixtures of metals such as: sodium, thallium and mercury; sodium, thallium, cadmium and mercury; lithium, thallium and mercury can be used to make metal vapour lamps suitable for general illumination.

Other embodiments for a wick electrode and tube shapes to receive it and provide at least some reservoir of liquid dose will be apparent to those skilled in the art. By way of a non-exhaustive list the following wick forms may be suitable for certain applications:

a) replacing a coiled coil with a braid made by repeated winding of tungsten wire on the electrode shank, each layer being wound in the opposite direction to the previous one, typically for three layers not necessarily of the same diameter;

b) a porous, pre-sintered tungsten ring;

c) a porous ceramic cylinder, preferably of sintered alumina made by embedding metal powder, preferably nickel, in alumina powder, sintering to give some strength without evaporating the metal, leaching out the metal with acid and re-sintering the porous structure at higher temperature;

d) a porous ceramic cylinder, as in c), but made with metal, preferably nickel, braid rather than powder;

e) a porous cermet material, made by coating ceramic (preferably alumina) granules with metal (preferably molybdenum or nickel), prefiring at 600 - 1200°C in an inert or reducing environment and subsequently leaching out the metal with acid and re-sintering the porous structure at higher temperature;

f) a porous cermet material made by dispersing metal (preferably tungsten or molybdenum) inside ceramic (preferably alumina) granules together with up to 25% by volume of an organic binder (preferably polyethylene glycol or polyvinyl alcohol) and subsequently burning out the binder during firing at 1000 - 1400°C (preferably 1200 - 1300°C) (An example of a porous cermet wick of this type is illustrated in Figure 17);

g) a structure as in e) but using other metal wire forms, porosity being controlled by the thickness and pattern of the wire;

h) a similar structure using molybdenum braid which can be sintered at a high enough temperature to embrittle the molybdenum and thus facilitate machining to shape before leaching out the metal;

i) a similar porous ceramic cylinder in which the metal used is iron which, being cheap, reduces the cost when prepared by leaching out;

j) a porous wick of metal, made by sintering metal flakes around the electrode shank, which can produce longitudinal voidage with greater strength than a porous sintered powder, this may be tungsten (preferably) or tantalum or molybdenum;

k) a wick made by sintering tungsten (preferably) or molybdenum powder containing a nickel wire structure, preferably braid, in which, to reduce the sintering temperature, 0.5 to 1.5% by weight of nickel being added to the tungsten powder and the nickel wire being leached out to leave pores for the wick;

l) a wick made by cutting tungsten wire into small pieces, pressing them around the electrode shank and sintering;

m) straight lengths of tungsten wire (or other high melting point, non-reactive metal) sintered together longitudinally parallel to the electrode shank, porosity being controlled by the sintering temperature;

n) a coil of tungsten wire as used for tungsten filament lamps, a suitable example being wire from tungsten halogen 'studio' lamps rated at 240V, 1500W;

o) one or more tubes of sintered alumina placed around the electrode shank so that the resulting annular spaces are dimensionally suitable for capillary action.

An effective wick may be provided by texturing or contouring the electrode shank surface provided the criteria for capillary action are satisfied. This may be achieved for example by a helical groove which is almost closed at the surface providing opposing surfaces for the capillary action, although at present such a surface would be difficult to produce.

Although tubes have been described with one conventional electrode and one wick electrode it is envisaged that successful tubes may have two electrodes both of which are wick electrodes. However at any time only one such electrode may be operative in a heat pipe mode depending on the tube orientation.

Furthermore although the illustrated embodiments show a wick disposed around the electrode shank it will be realised that it may be adjacent or in the region of the shank, perhaps disposed around an auxiliary electrode, providing it is wetted by the liquid dose.

What we claim is:

1. A high pressure discharge lamp including a light transmitting arc tube having, sealed into the ends thereof, electrodes each comprising at least an electrode shank and within the arc tube a dose suitable to be liquid at least in part at the working temperature of the lamp, the lamp further including a reservoir region adapted to collect the liquid dose when the lamp is appropriately orientated and transfer means arranged to be in contact with the liquid dose when the lamp is appropriately orientated and constructed so that, in operation, at least part of the liquid dose is moved to a hotter part of the tube by the action of surface tension.

2. A lamp according to Claim 1 in which the transfer member comprises a porous wick of a material suitable to be wetted by the liquid dose in operation.

3. A lamp according to Claim 2 in which the arc tube is made of silica and the porous wick is made of a material suitable to be wetted by a metal or metal compound melting at a temperature below 1000°C.

4. A lamp according to Claim 2 in which the arc tube is made of polycrystalline alumina and the porous wick is made of a material suitable to be wetted by a metal or metal compound melting at a temperature below 1100°C.

5. A lamp according to any preceding claim in which the transfer means is disposed in the region of the shank of one of said electrodes.

6. A lamp according to Claim 5 in which the transfer member is a wire braid wrapped around the electrode shank.

7. A lamp according to Claim 5 in which the transfer member is a wire coil disposed around the electrode shank.

8. A lamp according to Claim 5 in which the transfer means is a porous ceramic member.

9. A lamp according to Claim 5 in which the transfer member is a porous metal member.

10. A lamp according to Claim 8 or Claim 9 in which the electrode shank passes through the porous member.

11. A high pressure discharge lamp including a light-transmitting arc tube; two electrodes, each comprising at least an electrode shank sealed into opposing ends of the arc tube; within the arc tube a dose suitable to be liquid at least in part when the lamp is in operation; and transfer means disposed in the region of a least one of said electrode shanks and made of a material which will be wetted by the liquid dose at the operating temperature of the lamp so that in operation, with the lamp appropriately orientated, the transfer member is capable of moving some of the liquid dose to a hotter part of the lamp by the action of surface tension.

12. A lamp according to Claim 11 in which the transfer means is disposed around the electrode shank.

13. A lamp according to any of Claims 5 - 12 including a further transfer means disposed in the region of the other said electrode shank.

14. A lamp according to any preceding claim being a metal vapour lamp.

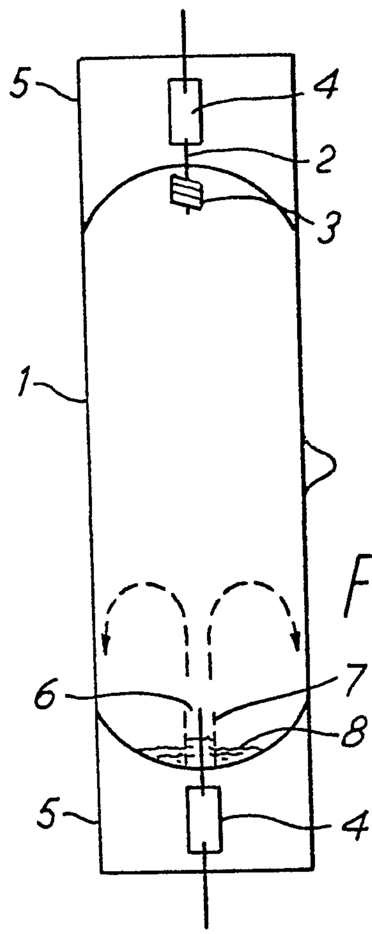

FIG.1

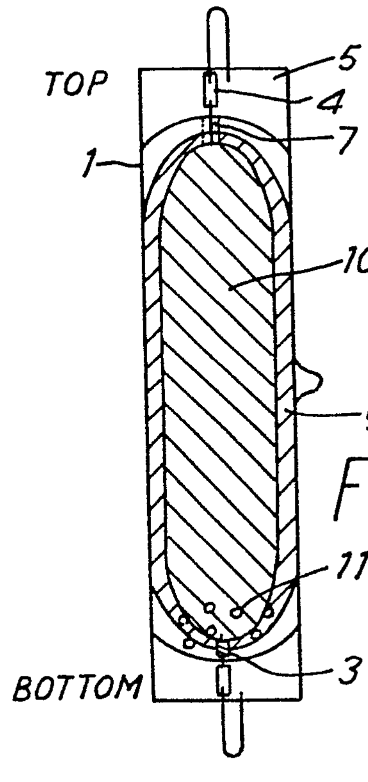

FIG.2

TOP

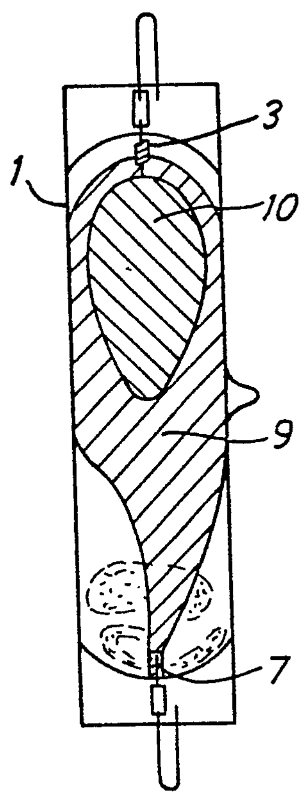

FIG.3

BOTTOM

2/7

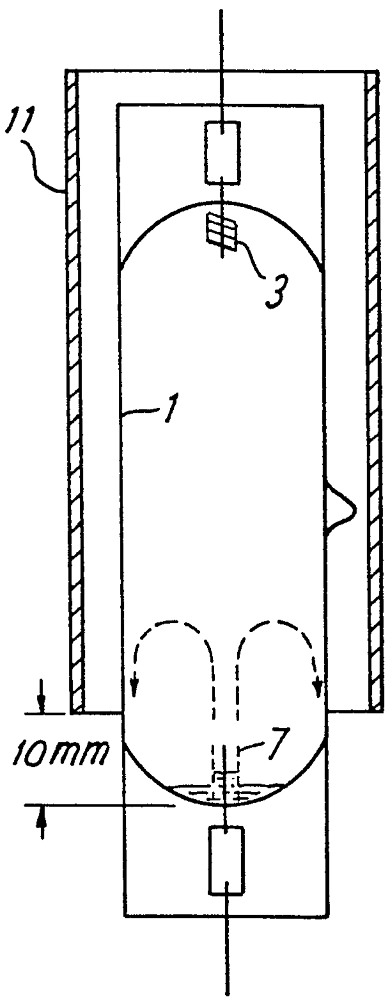

FIG.4

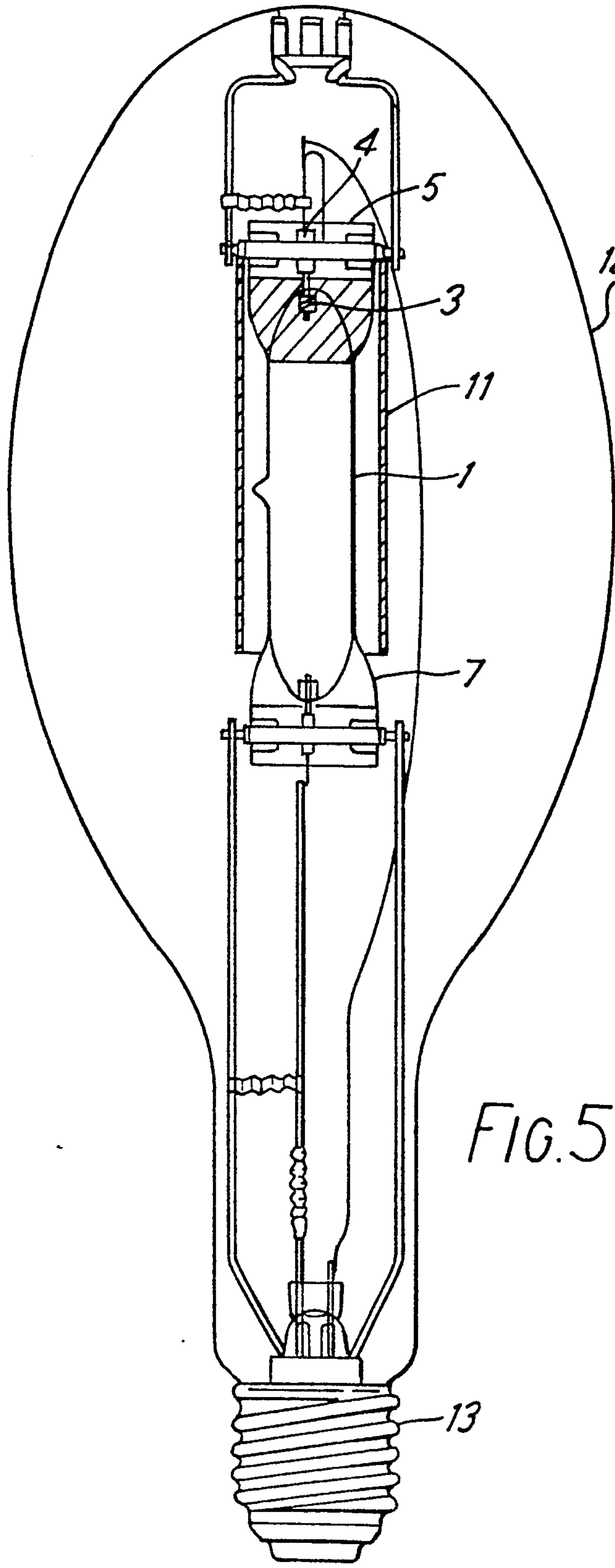

FIG.5

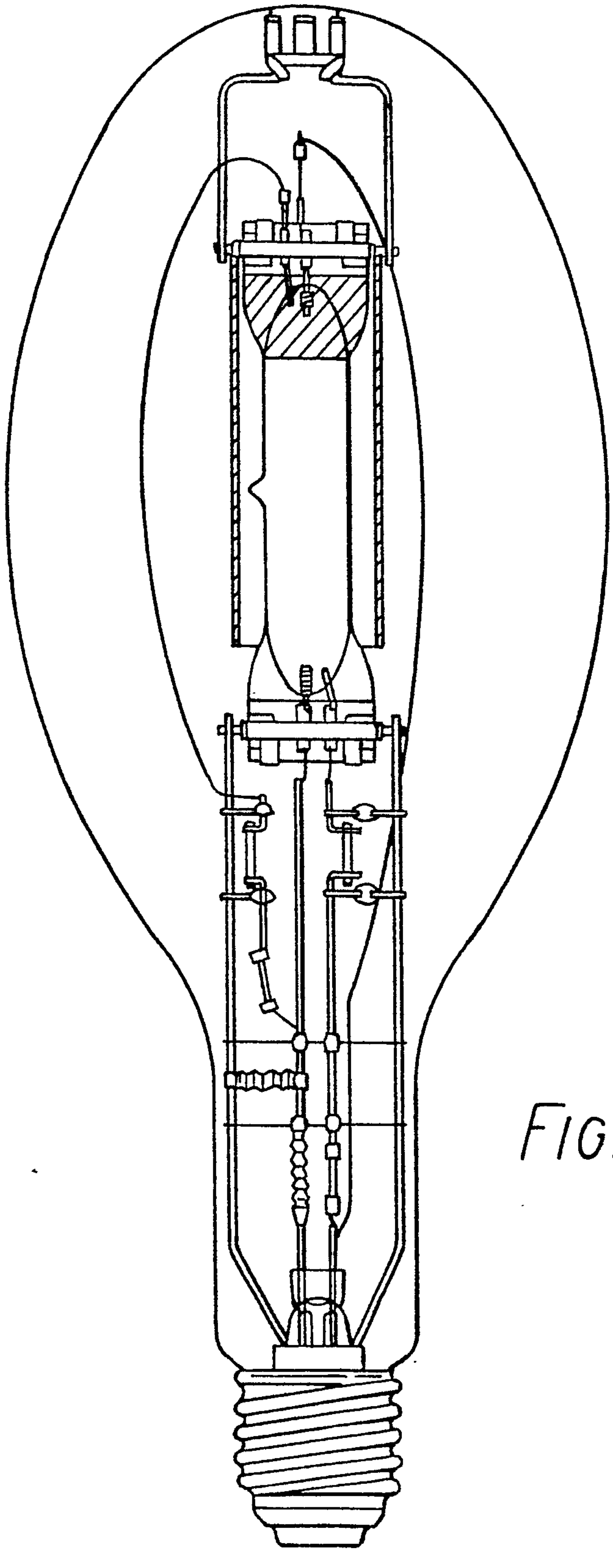

FIG. 5a

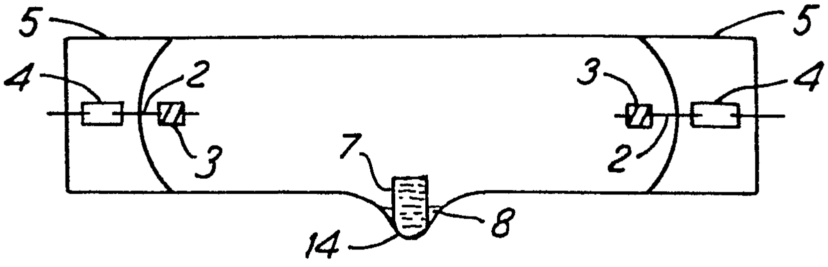

FIG. 6

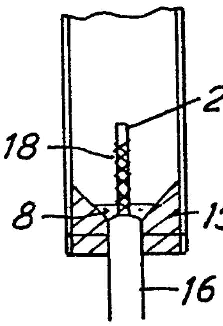

FIG. 7

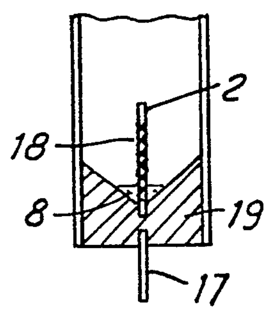

FIG. 8

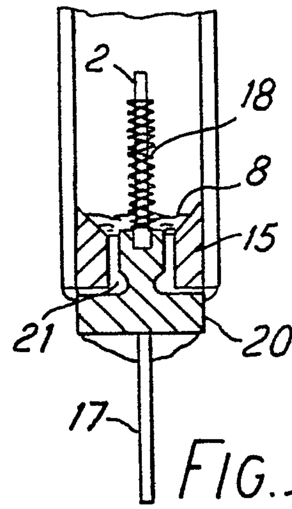

FIG. 9

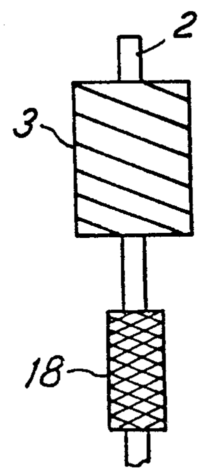

FIG. 10

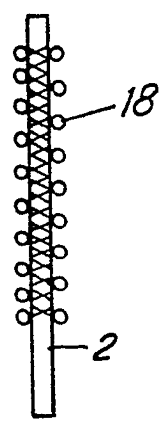

FIG. 11

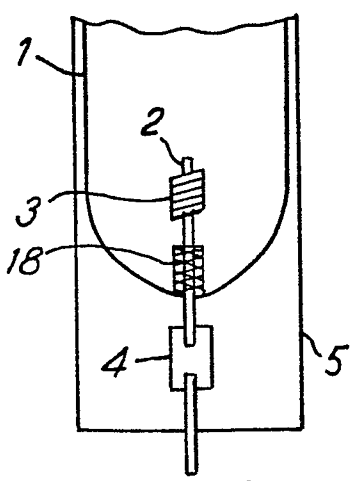

FIG. 12

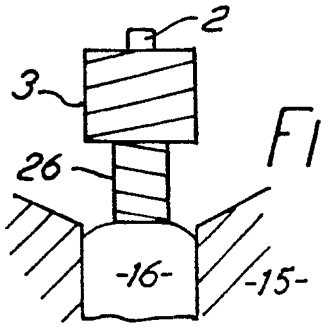

FIG. 13

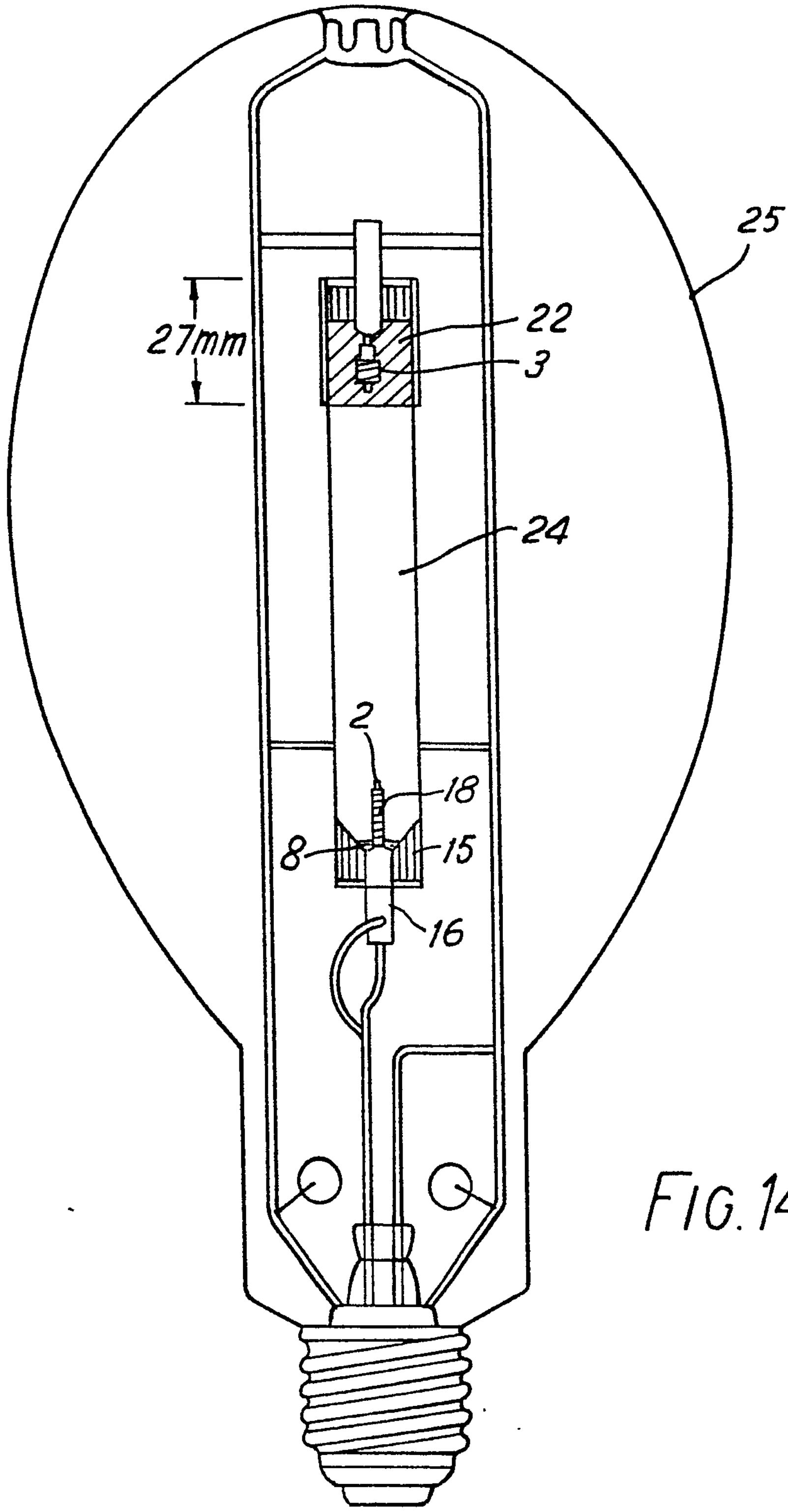

FIG. 14

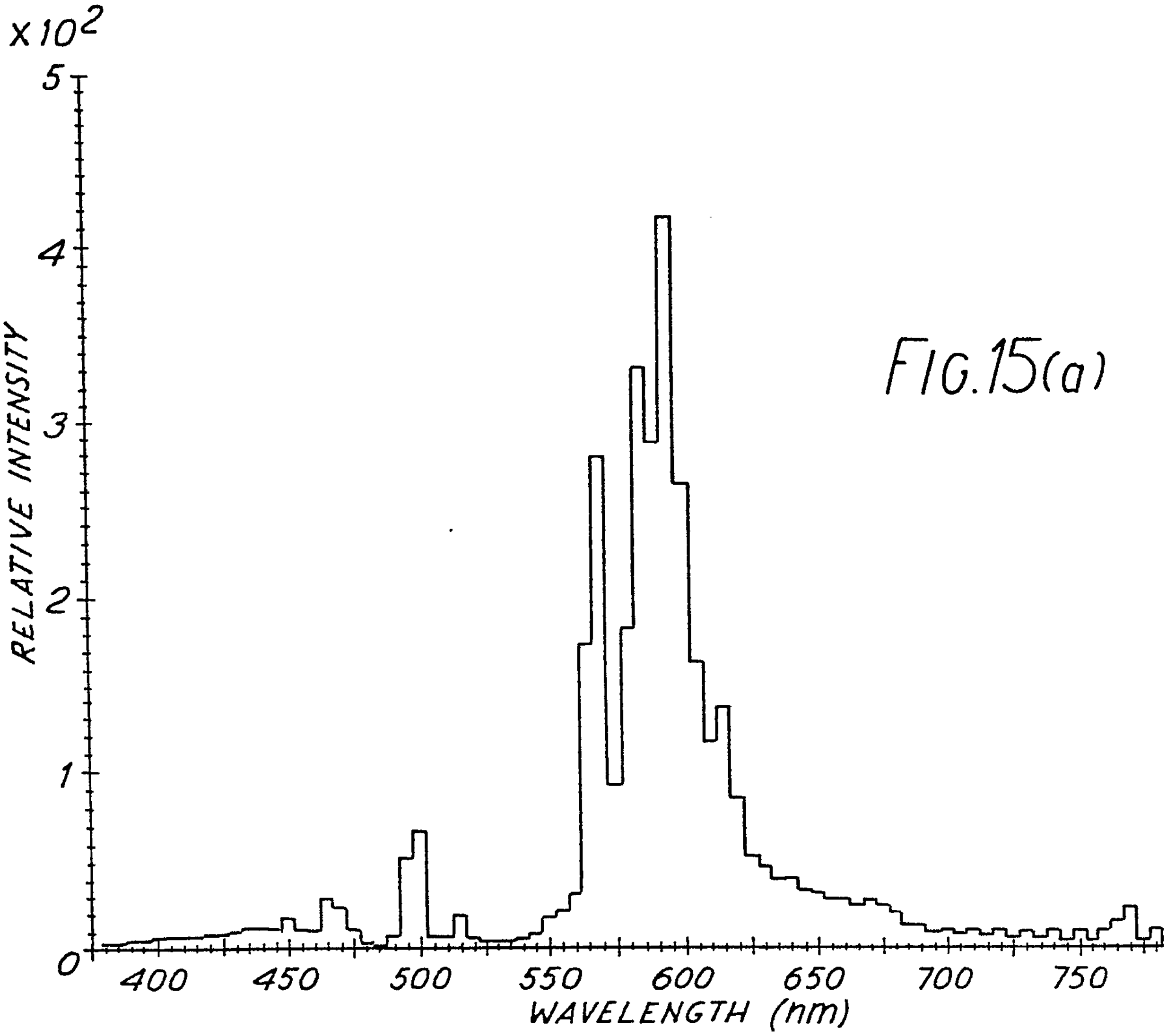

FIG.15(a)

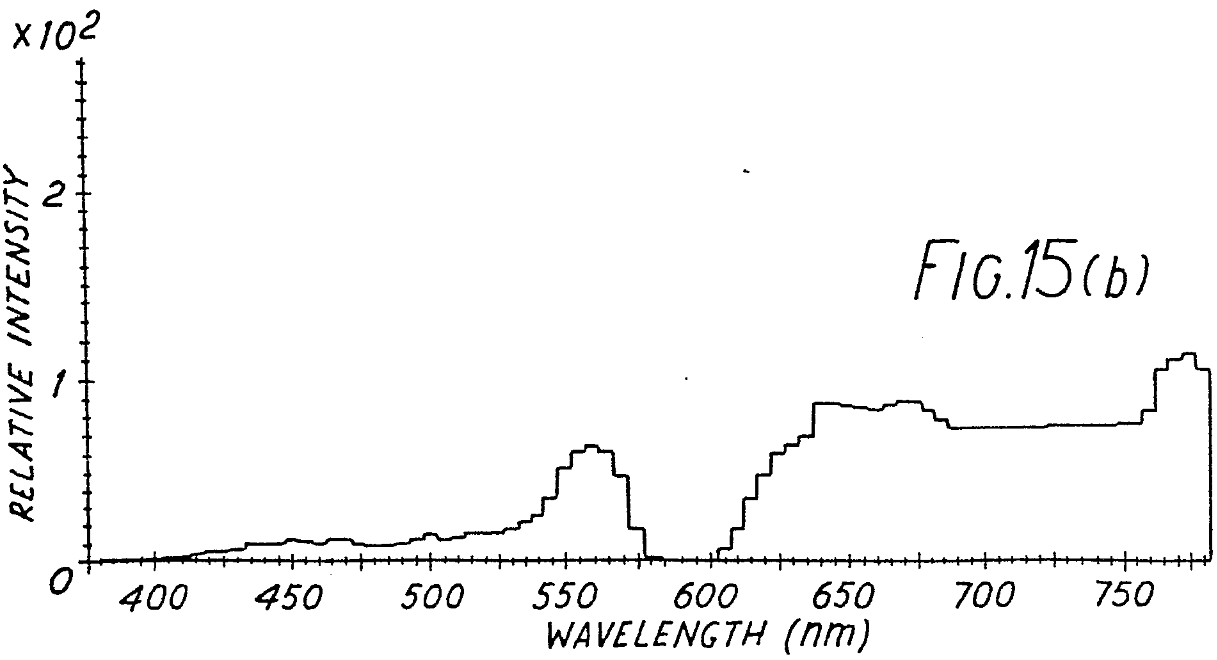

FIG.15(b)

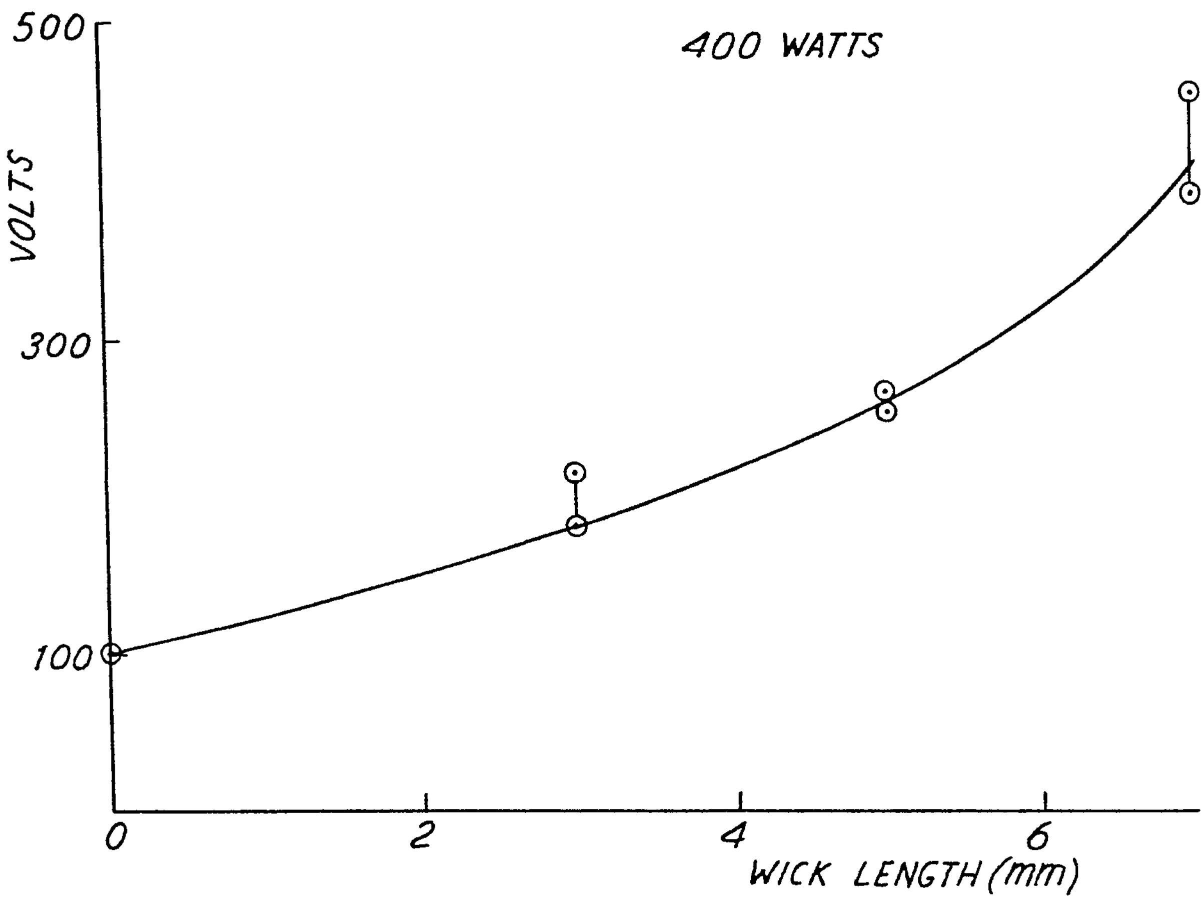

FIG. 16

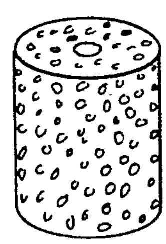

FIG. 17