Dec. 18, 1956 E. LEMMERS 2,774,918

ELECTRIC DISCHARGE DEVICE

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Fig. 1.

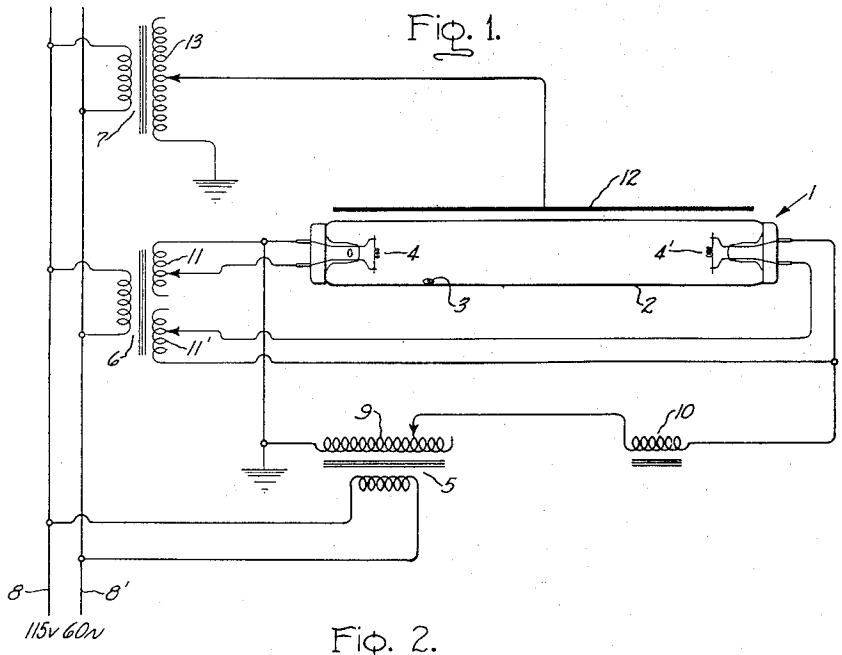
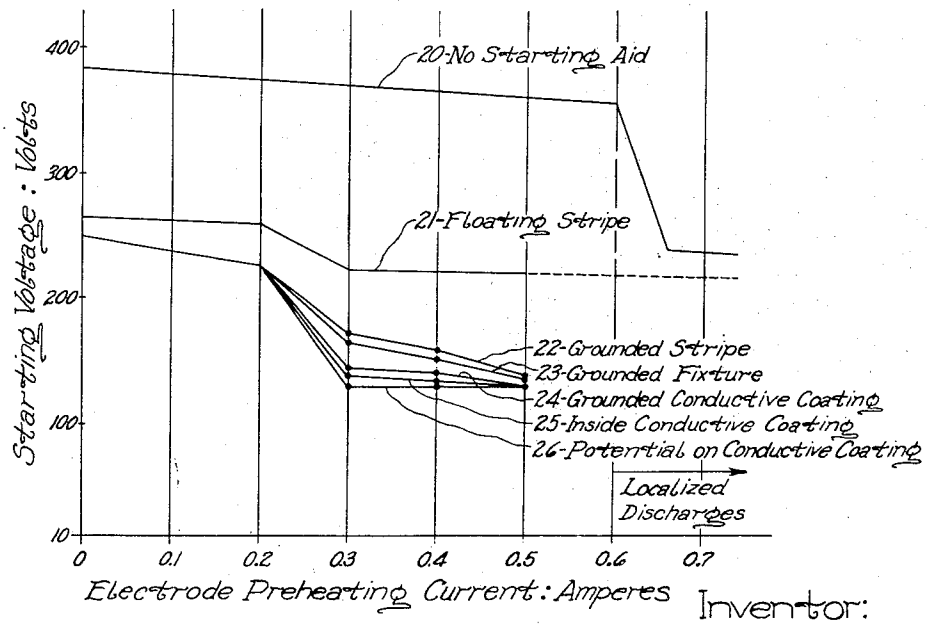


Fig. 2.



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Fig. 3.

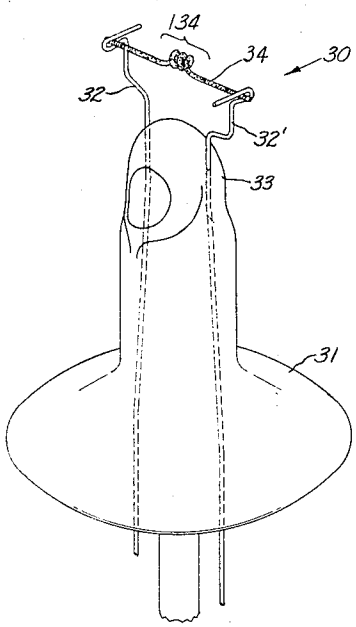


Fig. 3a.

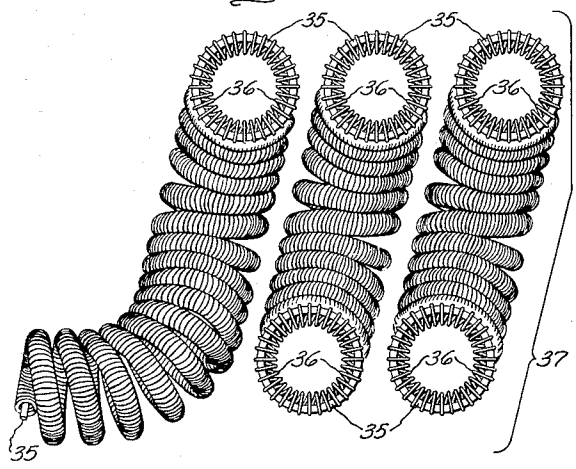
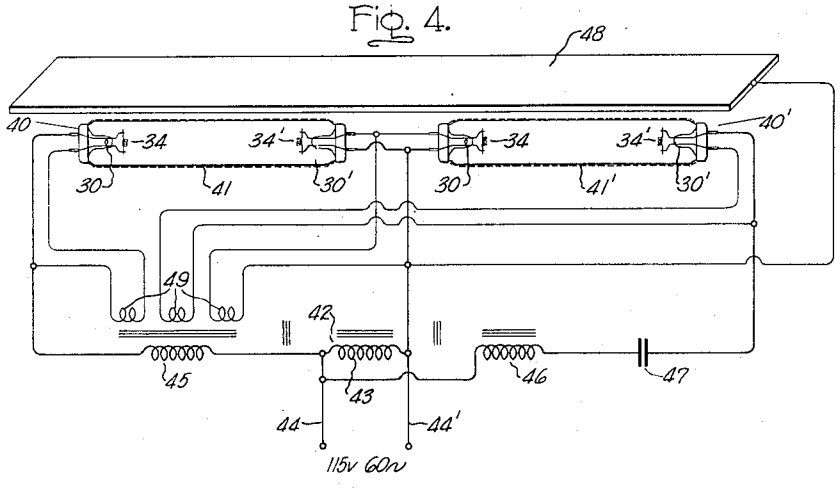


Fig. 4.



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Fig. 6.

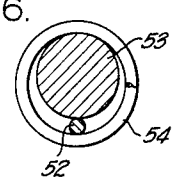


Fig. 7.

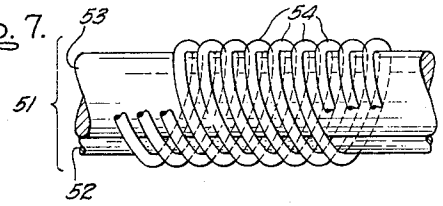


Fig. 5.

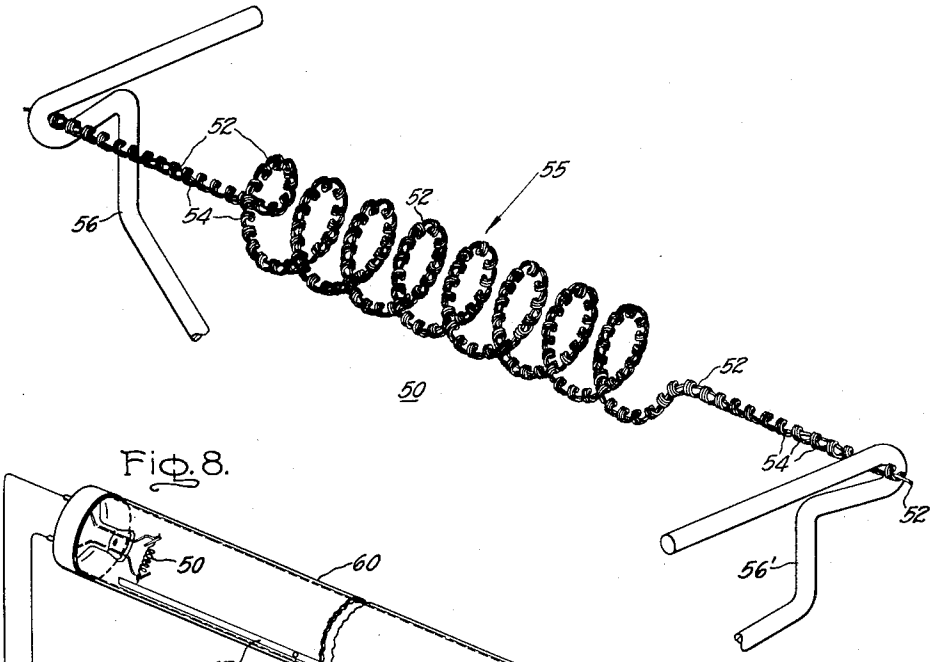
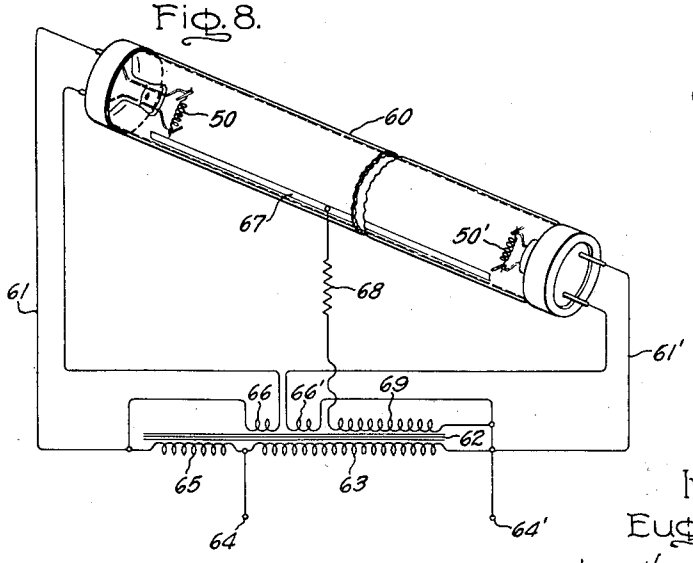


Fig. 8.



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Fig. 9a

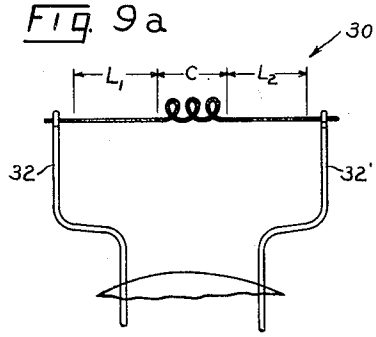


Fig. 9b

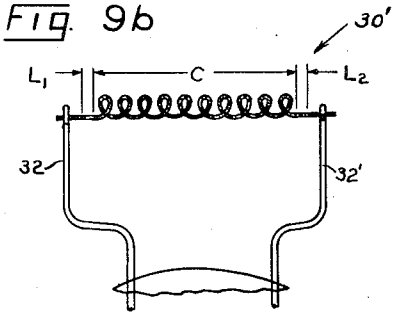


Fig. 10a

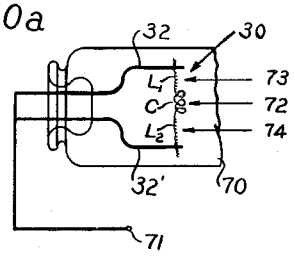


Fig. 10b

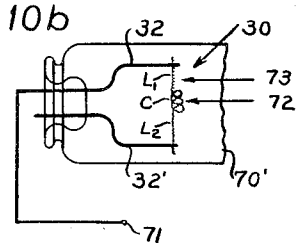


Fig. 10c

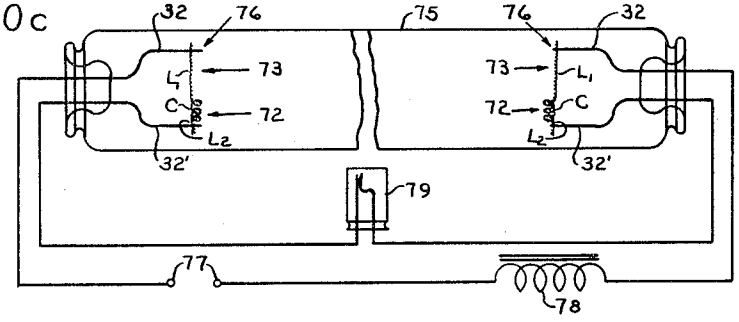


Fig. 11a



Fig. 11b

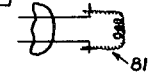


Fig. 11c



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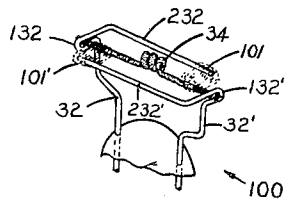
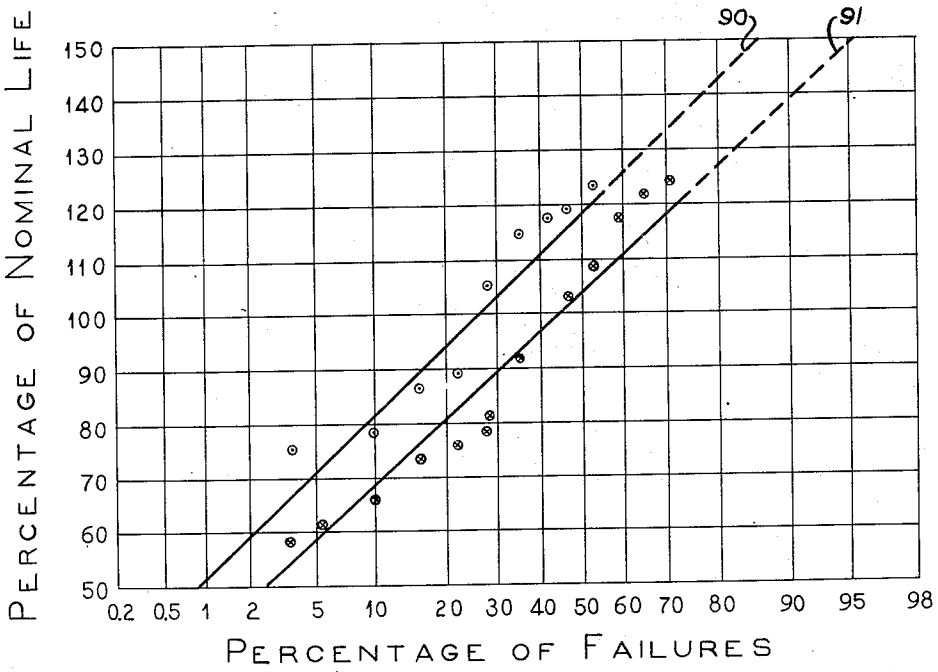


Fig. 13

Fig. 12



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United States Patent Office 2,774,918 Patented Dec. 18, 1956

2,774,918

ELECTRIC DISCHARGE DEVICE

Eugene Lemmers, Cleveland Heights, Ohio, assignor to General Electric Company, a corporation of New York

Application October 6, 1951, Serial No. 250,106

29 Claims. (Cl. 315—98)

This invention relates generally to gaseous electric discharge devices as typified by the common fluorescent lamp, and more particularly to an improved method of operating such devices, to improved device constructions and to improved electrode structures for deriving the maximum benefits from my new method of operation. The invention also provides an improved filamentary electrode structure for lamps utilized in existing systems of operation such as the switch-start and the instant-start systems, and which affords improved performance. The present application is a continuation-in-part of my copending application No. 211,126, filed February 15, 1951, entitled "Electric Discharge Device and Method of Operation," assigned to the same assignee of the present invention, and since abandoned. That application was a continuation-in-part of my earlier copending application No. 155,671, filed April 13, 1950, and since abandoned.

Present day commercially successful fluorescent lamps employing hot cathodes during operation may be divided into two broad categories, the hot starting lamp and the cold starting lamp.

The hot starting lamp is the type most commonly used for both commercial and home lighting applications. It is operated in conjunction with some means for momentarily passing a current through the lamp electrodes in order to preheat them for starting purposes; such means may, for instance, be glow or thermal type switches, as a result of which these lamps are generally known as switch-start lamps. The lamps start a few seconds after the line or control switch is closed, and quite often flicker a number of times before achieving steady operation. Hot starting lamps may also be operated with neutralizing windings instead of glow or thermal switches. The neutralizing winding is connected in a bridge network in the ballast, so that a bucking voltage is produced as a result of the discharge current of the lamp flowing through a suitable winding. After the lamp is started, the cathode heating current is reduced to a relatively low value in order to conserve energy and to prevent undue shortening of electrode life.

The cold starting or instant-start lamp is designed for use with high voltage ballasts which eliminate the need for starters. Although this lamp is commonly termed a cold starting lamp, the cathodes are actually heated very rapidly by an initial predischarge current and the arc occurs when ionization in the lamp has advanced sufficiently; thereafter the lamp operates with a hot cathode.

Both the hot and the cold starting lamps require rather elaborate starting and operating circuits. In the case of the hot starting lamp, either a switch or a neutralizing circuit is required in order to reduce the filamentary heating current after starting. In the case of the cold starting lamp, a very high voltage transformer is required in order to produce a sufficient potential across the lamp electrodes, previous to the starting of the main discharge, for ionizing the gaseous column of the tube. The flickering and delay in starting in the one case, and the cost

of the high voltage transformers in the other case, have been undesirable features of these systems.

It is an object of my invention to provide an improved and economical method of and circuit arrangements for operating a fluorescent lamp which dispenses with the need for either glow or thermal type switches or neutralizing windings for the filamentary heating circuits, and which does not require a high voltage transformer, such as is used with cold cathode starting lamps, for initiating the discharge.

Another object of my invention is to provide an improved fluorescent lamp construction which combines some of the features of the hot starting type with some features of the cold starting type, the result being a new lamp structure more economical than either and having greater flexibility in its circuit requirements.

Another object of my invention is to provide improved electrode structures especially suitable for discharge devices operated in accordance with my new method.

A further object is to provide an improved filamentary electrode structure of general applicability for discharge lamps, including lamps for present systems of operation such as the switch-start and instant-start systems, and which provides improved performance.

A feature of my method of operation is the use of very low power or wattage for heating the filamentary electrodes, and the starting of the main discharge without either high voltage or shock impulses.

Another feature of my method of operation is the use of low values of current for preheating the filamentary electrodes, the current being actually less than that required to produce localized discharges across the electrodes. The attendant rise in the starting voltage, required between the electrodes for initiating the arc, is then offset by the use of some auxiliary starting aid which accentuates the potential gradient in the immediate vicinity of the electrodes. As a result, the voltage which must be supplied by the ballast circuit at starting is augmented but very little if at all over that which would be required for a switch-start lamp wherein localized discharges are produced across the electrodes at starting.

Another feature of my new fluorescent lamp construction is the provision therein of filamentary electrodes which can be heated to electron emission with markedly smaller preheat wattages than have been used heretofore.

In accordance with one of the principal features of my invention herein illustrated, I provide a new and improved electric discharge device of the low pressure type, such as a low pressure fluorescent lamp, comprising an elongated envelope having therein spaced filamentary electrodes requiring relatively low energy consumption and preferably of the activated type, and wherein the device is provided with a stripe or complete coating of a material adherent to and integral with the envelope in order to facilitate the establishment and accentuation of an electric gradient within the vicinities of the electrodes.

One aspect of my invention is based on the discovery that there are definite and critical interrelationships existing among certain factors which may have been separately observed heretofore with regard to the starting and operating of electric discharge devices. One of these factors is the degree of preheating which must be provided to an electrode in order to achieve the first decided lowering of starting voltage. Another factor is the decided reduction in electrode disintegration during starting and the resulting increase in lamp life attendant upon the provision of a small degree of preheating to an electrode, even when such preheating is achieved with a voltage drop across the electrode much less than that required to produce a localized discharge. Another factor, according to my invention, is the effect of auxiliary starting aids extending the length of the lamp and accentuating the potential

gradient in the immediate vicinity of the electrodes. Such aids may be utilized to compensate for and offset a rise in starting voltage between the electrodes which might result from attempting to start a lamp without the production of localized discharges across at least one of the electrodes.

By correlating these diverse factors, I have discovered a new method of operating electric discharge devices, such as fluorescent lamps, which partakes of the advantages of both the switch-start and instant-start methods and which avoids the main drawbacks of both. My invention also provides new and improved fluorescent lamp constructions which permit the obtention of maximum benefits as to both lower initial cost of equipment and lower actual operating cost, through the application of my improved method of operation.

I prefer to call my new method of operating fluorescent lamps the "rapid start" method, and for the sake of simplicity, it is referred to in these terms throughout this specification.

In its broader aspects, my new method of operation achieves reliable starting of fluorescent lamps at relatively low voltages by providing a small value of preheating current, or more properly, of preheating wattage, to the electrodes. During normal operation, the preheating current to the electrodes may be not cut off but may be allowed to continue so that the need for thermal or glow switches or neutralizing windings is obviated. It will be realized of course that it would not be economical to operate a lamp such as the present switch-start lamps with their rated values of preheating wattage continuously supplied to the electrodes. For one reason, the electrodes would become overheated and would disintegrate quickly, and for another, the wattage loss in them would be prohibitive. By means of my new lamp construction incorporating small size activated filamentary electrodes, my new method permits the operation of a fluorescent lamp with a total wattage consumption, in the ballast and in the lamp, including the electrodes, comparable to that obtaining with a switch-start lamp and its ballast, and much less than that obtaining with an instant-start lamp and its ballast.

Although it might be thought that a reduction in the size of the electrodes might entail a much shorter lamp life, I have found that such is not the case. This appears to result from the fact that, whereas with my new method of operation the lamp starts comparatively quickly, the establishment of the cathode spot occurs relatively slowly and without destructive ionic bombardment. With switch-start or with instant-start operation, on the other hand, the establishment of the cathode spot occurs quickly and forcibly, due to the "inductive kick" type of starting in the former, and to the "brute force" high voltage type of starting in the latter. This statement may appear paradoxical when applied to switch-start lamps in connection with which the most objectionable feature is the well known slowness and delay in starting. Nevertheless, it is readily understood when it is recalled that the delay in the starting of a switch-start lamp is essentially the time taken to preheat the electrodes and, thereafter, to allow the glow or thermal switch to cool and re-open. The arc discharge in the lamp itself starts practically instantaneously when the switch re-opens, so that it is correct to state that the establishment of the cathode spot occurs quickly even though the lamp as a whole is subject to considerable delay in starting. Thus, I have found that when a fluorescent lamp provided with cathodes of the same type as are generally utilized for instant-start lamps, but which are cut down to ⅓ or ¼ their usual size, for instance by reducing the number of turns in the final coiling, is operated in accordance with my new "rapid start" method, it may have a life equal to if not superior to that of present commercial fluorescent lamps of either switch or instant-start types.

According to another aspect of my invention, a preferred embodiment of my improved fluorescent lamp construction is based on the premise that the different requirements of a cathode at starting and during operation may be disassociated and considered separately. It follows therefrom that a more efficient and economical cathode may be provided by designing a portion thereof specifically for minimum power consumption in starting, and another portion specifically for ability to withstand the rated discharge current during operation. In the case of ordinary switch-start lamps, the whole of the cathode is raised to electron emission at starting. Economic considerations then require that preheating be discontinued during normal operation in order to conserve the large wattage which would otherwise be dissipated. In the case of instant-start lamps, a cathode holding a relatively large amount of activated material must be provided in order to insure a reasonable operating life for the lamp. In accordance with this aspect of my invention, I combine features characteristic of the cathodes utilized in both types of lamps into a single cathode wherein a portion having a relatively low thermal capacity is heated for starting the lamp, and another portion carrying a comparatively large amount of activated material is utilized for supporting the arc during normal operation.

According to yet another aspect of my invention, it is possible to achieve a much more effective utilization of the tungsten wire and of the emissive material in the filamentary electrodes of discharge lamps made for present systems of operation. This I accomplish by decreasing the number of major turns and correspondingly increasing the length of the legs, that is, of the portions of the electrode which stretch from the major turns to the lead-in or support wires. This unique construction of the electrodes is particularly effective with instant start lamps, and it has enabled me to produce a lamp which may utilize as little as 50 percent of the tungsten wire and emissive material formerly throught necessary in order to secure the necessary length of life and lumen maintenance for such lamps.

For further objects and advantages and for a better understanding of my invention, attention is now directed to the following description and accompanying drawings. The scope of my invention will be more fully pointed out in the appended claims.

In the drawings:

Fig. 1 is a schematic diagram of a laboratory circuit for obtaining data with respect to the starting and operating of a discharge device and which may be used to illustrate the different methods of operation which are discussed in this specification.

Fig. 2 is a graph showing the starting voltages required for different values of preheating current to the cathodes of fluorescent lamps under various operating conditions.

Fig. 3 is a pictorial view of a cathode stem assembly for incorporation into a fluorescent lamp embodying my invention, and Fig. 3*a* is an enlarged view of a section through a portion of the filament.

Fig. 4 is a simplified diagram of a pair of fluorescent lamps embodying my invention. These lamps are provided with cathodes of the type illustrated in Fig. 3 and are connected in a circuit suitable for the application of my new method of operation.

Figs. 5, 6 and 7 are concerned with a further aspect of my invention wherein the filamentary electrodes in a lamp each contain two portions, one being designed to have a relatively low thermal capacity, and the other being designed to carry a relatively large amount of electron-emitting material. Fig. 5 is a perspective view of an improved cathode structure achieving the above feature and Figs. 6 and 7 are cross-sectional and side views respectively illustrating early stages in its manufacture.

Fig. 8 is a tilted side view of a positive column electric discharge device equipped with a type of cathode illustrated in Fig. 5 and connected in a circuit suitable for operation in accordance with my improved method.

Figs. 9*a* and 9*b* are side views of electrodes illustrating the proportioning of wire as between the major turns and the legs, for a preferred structure embodying my invention and for prior art structures, respectively.

Figs. 10*a* to 10*c* are simplified schematic diagrams of lamp circuits which will be referred to in explaining the principles underlying my new proportioning of turns in filamentary electrodes.

Figs. 11*a* to 11*c* illustrate variants of the long leg electrode illustrated in Fig. 9*a*.

Fig. 12 is a graph showing actual results obtained on life tests of two sets of instant start lamps respectively constructed with electrodes corresponding to Figs. 9*a* and 9*b*.

Fig. 13 is a pictorial view of a variant of my small size electrodes, specifically adapted to switch-start operation.

In order to simplify the detailed presentation of my invention, the remainder of this specification is divided under the following major headings:

1. Basic factors and principles
2. New circuits and method of operation
3. Improved lamp constructions
4. New electrode structure
5. Improved electrodes of general applicability
6. Lamp life and general considerations

1. *Basic factors and principles*

The factors and relationships underlying my invention will now be explained by reference to the curves of Fig. 2. These curves represent actual results obtained from tests conducted upon various lots of fluorescent lamps in suitable circuits, of which that illustrated in Fig. 1 may be taken as representative.

Referring to Fig. 1, the device **1** shown therein is a positive column electric discharge lamp, for example, a fluorescent lamp similar to the types now in commercial use. It comprises an elongated glass envelope or bulb **2** containing a rare gas such as argon at a pressure of a few millimeters, in combination with a small quantity of mercury indicated by the droplet **3**. The supply of mercury may exceed the amount which is vaporized during operation of the lamp so that its vapor pressure may vary between 4 to 20 microns depending upon the ambient temperature, the optimum being approximately 8 microns for a bulb temperature of 45 to 50° C. Sealed into opposite ends of the envelope **2**, are a pair of filamentary thermionic electrodes **4—4'**. These electrodes may be constituted by a coil of tungsten wire activated with a coating of alkaline earth oxides such as barium and strontium oxides. In the usual commercial lamp, the interior of the glass envelope **2** is coated with a fluorescent powder which converts the ultraviolet light, produced by the discharge through the mercury atmosphere, into visible light. For the purpose of measuring the lamp characteristics which are graphically represented in Fig. 2, device **1** is shown connected into a starting and operating circuit which comprises transformers **5**, **6** and **7**, each equipped with a primary winding connected for energization to a source of alternating voltage such as the usual 115-volt, 60-cycle commercial supply, at **8—8'**. The main discharge circuit for the lamp comprises the tapped secondary winding **9** of transformer **5** which is connected in series with a ballasting reactance **10** across the lamp electrodes. Various values of preheating current may be provided to the electrodes **4—4'** which are connected in circuit with the adjustable secondary windings **11—11'** of transformer **6**. The circuit combination also comprises an elongated conductive member **12** which runs the length of the lamp in close proximity to it and which may be provided with various values of potential by means of the connection to the adjustable secondary winding **13** on transformer **7**.

Referring to Fig. 2, the curves therein illustrate the characteristics of lamp **1** as regards starting voltage with respect to cathode heating current under various operating conditions. These curves are representative values obtained from large numbers of lamps similar to 40-watt instant-start fluorescent lamps commercially available.

Referring to Fig. 2, curve **20** illustrates the starting voltage chracteristics of device **1** in the absence of the capacitive member or plate **12** and under low humidity conditions. It will be understood that the capacitive member **12** is removed entirely from the vicinity of the lamp and is not merely disconnected from the transformer **7**. When no preheating current is supplied to the electrodes, this condition corresponding to the abscissa zero on the graph, the starting voltage is approximately 380 volts. It will be observed that, as the electrode preheating current is increased up to approximately 0.6 ampere, there is very little reduction in the starting voltage required. From 0.6 to 0.65 ampere, the voltage drop across the ends of either electrode is approaching the ionization potential of the mercury vapor and in this region the required starting voltage drops quite rapidly. In this range, the ionization potential of mercury, namely 10.4 volts, is exceeded and local discharges appear across the ends of the electrodes. It will be understood that by a local discharge it meant a discharge connected with a single electrode and occurring across its ends and not a discharge between two electrodes. Any further increase in the electrode preheating current beyond this range produces little additional lowering of the starting voltage.

Curve **21** illustrates the starting voltage characteristic when the capacitive member **12** takes the form of a narrow conductive band deposited on or attached to the envelope of the lamp and left floating, that is, not connected to any source of potential and not grounded. Such a conductive band applied to the outside of a fluorescent lamp along its length is generally referred to as a stripe, and it may be a ribbon of silver deposit or of colloidal graphite painted thereon. Now, in the absence of preheating current, the starting voltage is approximately 265 volts. As preheating is increased, the starting voltage drops slowly. However, it will be observed that a comparatively rapid lowering of the starting voltage occurs in the region of preheating between 0.2 and 0.3 ampere, corresponding to temperatures approaching 500° C. Beyond this region, the rate of decrease of starting voltage is much lower and no further sudden lowering occurs, even when the characteristic is extended into the region wherein localized discharges begin.

Curves **22** through **26** illustrate the starting voltage characteristics for similar lamps under the various forms which may be assumed by the capacitive member **12**. In curve **22**, member **12** is a stripe, that is, a narrow conductive ribbon extending the length of the lamp, as described with reference to curve **21**, except that now the stripe is grounded. It will be observed that in the region of cathode preheat from 0.2 to 0.3 ampere, the starting voltage is lowered appreciably from the condition where the stripe is left floating, that is, unconnected to any reference voltage point. Curve **23** illustrates the starting voltage characteristics where the capacitive member **12** is simply a grounded metal plate such as is utilized with commercial fixtures for mounting the end sockets holding the lamp. With reference to curve **23**, this reservation must be made that it is applicable only in the case of a perfectly dry lamp or where some means such as a "hydrophobic," or moisture film prohibiting coating, is provided for preventing the formation of a moisture film upon the envelope of the lamp. Curve **24**, illustrating the characteristic for a grounded conductive coating shows a slight further lowering of the starting

voltage. The conductive coating in this case may consist of a transparent coating of stannous chloride which may be sprayed and baked on the envelope of the lamp. Curve 25 illustrates the starting voltage characteristic when the conductive coating is located inside the glass envelope of the lamp; it may likewise in this case be constituted by a coating of stannous chloride. Curve 26 illustrates the characteristic when a potential of approximately 300 volts is applied to a conductive coating upon the exterior of a lamp containing argon as the starting gas.

Consideration of the starting voltage characteristics shown in Fig. 2 has led me to the conclusion that all starting aids which run the length of a lamp function in a basically similar manner. These characteristics, which may be termed starting voltage-electrode excitation characteristics, show the effectiveness in starting lamps with lowered voltage applied between the electrodes and appear to be dependent upon three things. Firstly, by establishing a voltage gradient steeper than usual near the electrodes, they initiate a glow at a relatively low voltage. Secondly, they cause this glow to spread down the length of the tube by reason of the accentuation of the potential gradient, and, in the case of a mercury lamp containing argon as a starting gas, by photo-ionization in addition. Thirdly, by furnishing enough current to the glow so that, when added to the current supplied directly to the electrodes by the main circuit, the glow discharge swings out of its initial positive volt-ampere characteristic to a negative characteristic, they facilitate the transition into normal operation characterized by an arc discharge in mercury vapor.

It will be observed that all the starting aids considered in Fig. 2 modify the starting voltage characteristic in a basically similar fashion. Their most noticeable effect is to shift the region of sudden lowering of starting voltage to the left, that is to a point of lower preheating current. Thus, in the absence of a starting aid as illustrated in curve 20, the sudden lowering of starting voltage occurs in the region from 0.6 to 0.7 ampere; in all the other curves, which illustrate the characteristics of lamps provided with longitudinal auxiliary starting aids, the sudden lowering of starting voltage occurs in the region from 0.2 to 0.3 ampere. It will be understood that the specific current values shown in Fig. 2 apply only to the particular electrode used; however other electrodes having different resistances will in general show similar characteristics if operated on currents producing like temperatures.

The scientific theory for this phenomenon appears to be as follows, although it will be understood that I do not wish to be bound by its accuracy. With the particular electrodes with which the lamps used in these experiments were provided, a preheating current of 0.3 ampere corresponds to an electrode temperature of approximately 500° C. These electrodes were activated with alkaline earth oxides such as barium and strontium oxides, which achieve sizeable thermionic emission with greatly diminished cathode fall in potential at this temperature. For instance, the cathode fall may be down to less than 22 volts, that is, below the disintegration voltage in mercury vapor. In the case of the lamps provided with an auxiliary starting aid running the length of the lamp, the potential gradient in the immediate vicinity of the electrodes is accentuated so that when appreciable thermionic emission occurs, the potential gradient is sufficient to draw the electrons away from the vicinity of the electrode and a feeble glow appears. In the absence of an auxiliary starting aid, however, the potential gradient in the immediate vicinity of the electrodes is not sufficient to attract sufficient electrons away from it, so that a glow can appear only if the potential applied between opposite electrodes of the lamp is raised to a considerably higher value. Such would correspond to the case of an instant-start lamp not provided with any starting aid, for which the required starting voltage with a preheating current of 0.3 ampere is approximately 370 volts. A lamp not provided with a starting aid obtains its first decided lowering of starting voltage at much higher values of electrode preheating current, in fact at values producing a voltage drop across the ends of one electrode equal to or greater than the ionizing potential of mercury, namely 10.4 volts. When such a value of preheating current has been attained, a localized arc or discharge occurs across opposite ends of each individual electrode and thereafter this localized discharge can spread throughout the length of the lamp upon the application of a considerably lower starting voltage.

Irrespectively of the explanation, the curves of Fig. 2 establish the following basic relationship among the diverse factors which affect the starting voltage characteristics of discharge devices: lowering of starting voltage which may be achieved by means of preheating current through the electrodes sufficient to produce localized discharges across their ends, may in general likewise be achieved by preheating the electrodes to a temperature sufficient merely to produce appreciable thermionic emission without producing localized discharges and by adding some means for accentuating the potential gradient in the immediate vicinity of the electrodes. Stated in another way, the addition to a lamp of some means for accentuating the potential gradient in the immediate vicinity of the electrodes permits a reduction in the value of preheating current or wattage from that necessary to produce localized discharges to that sufficient merely to heat these same electrodes to electron emission, and the required starting voltage across the lamp in the latter case is as low as if not lower than in the former.

2. New circuits and method of operation

My new method of operating discharge devices such as fluorescent lamps follows from the application of my discovery above and comprises starting the lamp by preheating the electrodes merely up to the temperature of electron emission without raising the preheating current up into the region where localized discharges would take place. Additionally, the potential gradient in the immediate vicinity of the electrodes is accentuated by suitable means in order to take full advantage of the precipitous drop in the required starting voltage which occurs under these circumstances when the electrodes attain the temperature of electron emission.

Any of the various starting aids extending the length of the lamp which have been described, may be used in circuit arrangements applying my new method of operation. The simplest starting aid, of course, is the grounded conductive fixture. However, it is apt to be the least effective because the capacitive effect of the fixture upon the lamp is what is relied upon, and that effect naturally depends upon the spacing between the fixture and the bulb of the lamp. With the usual two pin fluorescent lamp sockets or holders which are commonly utilized in the industry, the spacing between the lamp and the front metal plate of the fixture is approximately ⅜". The characteristic illustrated by curve 23 in Fig. 2 was obtained with such a fixture under low humidity conditions. It will be understood that if the fixture is further removed from the lamp, its effectiveness as a starting aid is reduced.

In general, the use of the fixture itself as the starting aid for the lamp is very attractive because of its cheapness and simplicity. To make it practical, it is necessary to provide some means for preventing the formation of a film of moisture on the lamp under certain conditions of humidity, as a film of moisture may interfere with the capacitive effect of the fixture. I have obtained very satisfactory results by coating the lamp with a water repellent film such as a hydrolized organosilicon halide as described in U. S. Patent 2,408,822—

Tanis, assigned to the same assignee as the present invention.

A conductive stripe such as a narrow ribbon of silver or graphite deposited on the lamp bulb, either grounded or connected to one end of the lamp, functions in the same way as a grounded fixture. If a stripe is provided having a substantial width, the glow is initiated at a lower voltage and the capacitive effect is greater, so that more current flows and the lamp starts at a lower voltage. Humidity actually improves the starting of lamps with this type of starting aid because the moisture film on the bulb increases the effective conductive area of the stripe, thereby providing a greater capacitive effect.

With regard to the use of a conductive coating covering the whole of the bulb of the lamp as a starting aid, it is very effective and entirely satisfactory. Whether or not it is desirable to use it for any particular application in lieu of a stripe or of a fixture must be resolved by economic considerations. As regards a conductive coating inside the bulb of the lamp, it is also very effective as a starting aid but is rather difficult and costly to make.

3. *Improved lamp constructions*

Although I have thus far described a new method of operating discharge devices which can be applied to any of the common types of fluorescent lamps presently on the market, including both switch-start and instant-start lamps, it will be realized that in order to derive the maximum benefits from my improved method, it is necessary to adapt the lamp to the purpose. A switch-start lamp is usually provided with a simple type of cathode consisting of a coiled-coil of tungsten wire coated with activated electron emitting substances. In the switch-start method of operating such lamps, the preheating current to the electrodes is discontinued during normal operation. Accordingly, no consistent effort has been made to keep the thermal mass or capacity of the electrodes at a very low value. With the instant-start lamp, the cathodes have generally consisted of a coiled coil of tungsten wire, over whose minor turns a finer tungsten wire is wound into overwind convolutions. With this type of cathode, the major consideration has been to provide a large amount of electron emitting material on the cathode and such overwind convolutions assist in retaining the material.

With my improved method of operation, since the lamp starts after the cathodes have reached electron emitting temperatures, the amount of electrode disintegration at each start is comparatively insignificant. Accordingly, it is not necessary to provide as large an amount of electron emitting material as in the instant-start type of cathode. Moreover since only a small value of preheating current is required, it becomes feasible to allow the preheating current to continue to flow through the electrodes during normal operation of the lamp. It will be realized of course that this would not be practical with the prior art switch-start type of lamp because the wattage which would be wasted in the electrodes during operation would be prohibitive. I have found that by using a fraction only of the type of electrodes which are commonly used to instantly start lamps, it is possible to permit the preheating current to continue during normal operation because the wattage dissipated in the electrodes is so small that it can be tolerated. In fact, with my improved lamp construction and with operation in accordance with my new method, the total wattage consumed in the ballast and the lamp, including that wasted in the filaments, is considerably less than that consumed in an instant-start type of lamp with its ballast, even though such a lamp does not consume any wattage in heating the electrodes, except, of course, by the effect of the discharge.

A type of electrode which I have found suitable for for my improved lamp construction is illustrated in Fig. 3, included in a stem assembly **30**. The assembly comprises a glass base structure **31**, through which a pair of lead wires **32**—**32′** project vertically upward, passing through a flattened press **33**. The filament **34** is mounted on the lead-in wires **32**—**32′** and comprises three major turns. It is of the coiled-coil construction but is provided with overwind convolutions on the minor turns, as may be seen in Fig. 3*a*. It may be fabricated utilizing round wire **35** of 2.35 mil tungsten to constitute the minor turns, and round wire **36** of 0.7 mil tungsten to constitute the overwind convolutions. The electrode may be fabricated by starting off with the round wire **35** and an additional filler wire of 3.5 mil molybdenum to constitute a composite mandrel over which the wire **36** is wound at 530 turns per inch. This assembly may then be wound on a round mandrel of 10.0 mil molybdenum wire at 104 turns per inch to effect the minor coiling illustrated generally at **37**. This aggregate may in turn be wound on a round mandrel of 25.6 mil molybdenum at 10 turns per inch to effect the major or final coiling. After setting of the tungsten by suitable heat treatment and elimination of all of the molybdenum wires by dissolving in acid, three major turns, that is three turns of the final coil as shown generally at **134**, may be used for each cathode with additional lengths or legs of the minor coiling extending therefrom for welding or clamping to the lead supports **32**—**32′**. This cathode incorporates in general the teachings of U. S. Patent 2,073,885 to Spanner et al. In construction, it is generally similar to those described in U. S. Patent 2,306,925—Aicher to which reference may be made for more complete details as to the process of manufacture, and particularly that shown in Fig. 3 of the Aicher patent. However, the distinctly new and improved results of my invention may be obtained by employing only three major turns with relatively long legs, instead of 9.5 turns with very short legs as preferred in the Aicher patent, for a 48-inch, 40-watt fluorescent lamp of the instant-start type.

An improved fluorescent lamp in accordance with my invention may be made comprising two cathode stem assemblies **30** of Fig. 3, mounted in mutually facing positions at opposite ends of an evacuated glass envelope of the elongated tubular type to constitute devices such as **40** and **40′** shown in Fig. 4. It will be understood that the electrode coils **34** and **34′** are coated with suitable activating material such as barium, strontium, and calcium carbonates or mixtures thereof previous to mounting within the glass envelope, and that the lamp is completed in accordance with the usual manufacturing processes. These include activating the electrode by passing a heating current through them to reduce the carbonates to oxides, evacuating the envelopes, and thereafter introducing a small quantity of mercury and a starting gas such as argon into the envelopes.

Since these lamps are to be used in accordance with my improved "rapid start" method of operation, it is necessary to provide some means to permit accentuation of the potential gradient in the immediate vicintiy of the electrodes at starting. As has been explained heretofore, such additional means may take the form of a conductive strip on the envelope, or of a conductive coating, or again of a "hydrophobic" coating in which latter case the lamp is operated in a grounded conductive fixture located close to the envelope.

The arrangement of Fig. 4 operates the lamps **40** and **40′** in association with a grounded conductive fixture, and the envelopes are coated with a water-repellent film of the type described heretofore and more fully explained in U. S. Patent 2,408,822—Tanis. The "hydrophobic" coatings at **41** and **41′** on the lamps are indicated by the dotted lines, since it will be understood that the coatings are transparent and invisible. The lamps **40** and **40′** are energized by the lag and lead circuits respectively of a high reactance transformer **42** whereof the primary winding **43** is adapted to be connected to the usual 115-volt, 60-cycle commercial supply at terminals **44**, **44′**.

The secondary windings 45 and 46 are connected between the high side of primary winding 43, each to one side of lamps 40 and 40' respectively, the other sides of the lamps being connected in common to the low side of primary winding 43. A capacitance 47, which has a reactance equal to approximately twice the leakage reactance of winding 46 is connected in series with that winding in order to operate lamp 40' on a leading power factor. The arrangement operates the lamps in close proximity to a metal fixture, which, for the sake of convenience, has been represented by the rectangular metal plate 48. It will be understood that in practice this rectangular metal plate is simply the facing plate of the fixture. With the usual type of lamp holders or sockets utilized in the industry, the lamps are located at a distance of approximately ⅜" from the fixture. The filaments 34, 34' are connected to the heater windings 49 which provide heating current both at starting and during normal operation. The arrangement whereby the heater windings 49 are coupled to the lag winding 45 provides a factor of safety in case a lamp with shorted pins, such as a commercial instant-start lamp, were inadvertently inserted into the sockets of the fixture. In such case, the lamp would obviously fail to start but the total current drawn by the ballast circuit or transformer would not exceed the design rating and no dangerous overheating would occur.

In an actual construction of an embodiment of the invention in accordance with Fig. 4, lamps 40 and 40' are 40-watt low pressure fluorescent lamps approximately 48 inches long and 1½" in diameter. The lamps are equipped with cathodes of the type, which have been described with reference to Fig. 3, the starting gas filling is argon at a pressure of approximately 3 mms., and the lamps contain the usual small quantity of mercury. The "hydrophobic" or water-repellent coating on the lamps is of the silicone type and was made by the hydrolysis of methylchlorosilane. It may be produced by exposing the lamps for a few minutes to the vapor of methylchlorosilane in a suitable enclosure maintained at 50% relative humidity.

For achieving operation of the lamps in accordance with my "rapid start" method, the transformer ratings may be as follows: primary winding 43 115 volts; secondary windings 45 and 46, 220 volts open circuit when measured from the low side of winding 43. The heater windings 49 provide a voltage of 3.5 volts which results in a heating current of 0.38 ampere through the electrodes. Thus the wattage dissipated in the electrodes at starting and, subject to further qualifications herein, during normal operation, is approximately 1⅓ watts per electrode. With the electrode construction described, such a wattage raises the electrodes from room temperature to approximately 550° C. in slightly less than ½ second at which point the lamps start. The wattage dissipated in the electrodes would cause them to reach, eventually, a temperature of approximately 900° C. at which point equilibrium is achieved and the heat loss from the electrodes by radiation is equal to the input.

Since the wattage dissipated in the electrodes is so low, that, is less than 2 watts per electrode, it is entirely feasible and practical to allow the hetaing of the electrodes to continue during normal operation. In this particular case, the apparent wattage loss in the lamps due to allowing current to continue to flow through both electrodes is approximately 7% of the lamp rating. In view of the remarkable advantages of the "rapid start" method and lamps, both as regards the elimination of the annoying flickering and delay of switches, and as regards the elimination of the cost of such switches, a loss in the electrodes of as much as 10% of the rated lamp watts may readily be tolerated.

However, part of the 7% loss previously mentioned is an apparent loss only, and only approximately half of this percentage is actually wasted. The explanation for this appears to be that the continuous heating of the cathodes by the "preheating" current lowers the cathode fall in potential and permits the lamp to operate at the same discharge current with a lesser energy consumption in the arc. In addition, by properly poling the connections from the electrodes to the heater windings, the discharge current may be made to neutralize in part the electrode heating current, although this effect will vary with the shifting position of the cathode spot during the life of the lamp.

By way of example, the circuit of Fig. 4 operating a pair of 40 watt "rapid start" lamps as described, consumed a total of 100 watts for normal light output. This wattage includes all ballast or transformer losses, plus the arc wattage, plus the electrode heating losses. Upon disconnecting one side of each cathode heating circuit and readjusting the line voltage to obtain the same measured light output as before, the total circuit consumption is 98 watts. This figure now includes the same ballast or transformer losses, plus the arc wattage. The difference of 2 watts between the figures in the two cases is thus seen to be the additional loss incurred through nonremoval of the electrode "preheating" current during operation, and it amounts to ½ watt per electrode only. In other words, the actual operating loss due to continuous heating of the cathodes is 1 watt per 40 watt lamp, that is, 2.5% of the lamp rating, and much less than 10%. However, even were the additional loss as high as 10%, it is still less than the additional transformer loss incurred through the use of high voltage very high leakage reactance transformers in instant-start circuits.

In the above discussion of my new lamp structures, I have described specifically the electrode configurations and preheating wattages for a 40-watt, 48-inch tubular fluorescent lamp. It will be understood however that my invention is equally applicable to other sizes of lamps. In general, the electrode size in a lamp varies with the discharge current. However, commercial fluorescent lamps of the tubular elongated type are generally rated in watts and designated by their nominal wattage. Since the voltage drop per unit length of lamp is substantially constant, the nominal wattage divided by the length in feet is generally proportional to the current rating and may be used as a figure affording a practical basis of comparison for the preheating wattages required for different sizes of electrodes. It will be realized however, that this basis of comparison, whereas it is more convenient than the current rating, is approximate only, since certain factors, such as the constant electrode losses, are neglected. Stated in another way, the electrode size is generally proportional to the rating of a lamp in watts divided by its length in feet.

In accordance with my invention, my improved "rapid start" lamps are provided with cathodes of small size or physical configuration providing a low thermal loss characteristic such that they may be raised to thermionic emission, that is, to a temperature between 500° and 900° C., by means of preheating wattage less than 20% of the nominal lamp wattage per foot, for each electrode. By comparison, present commercial switch-start lamps are generally designed to consume a preheating wattage equal to 50% or more of the lamp wattage per foot in order to produce localized discharges. When such lamps are operated in accordance with my "rapid start" method, they require in excess of 20% of the lamp wattage per foot for preheating each electrode to thermionic emission, and such wattages are generally too high to be wasted during normal operation. In other words, my new "rapid start" lamps, by reducing the required preheating wattage to less than 20% of the arc wattage per foot, make it economically feasible to allow the preheating wattage to waste during normal operation, whereas present commercial fluorescent lamps do not.

The following table gives the approximate electrode preheating wattages for various sizes of present commercial switch-start lamps, firstly in order to produce localized discharges for starting, and secondly in order merely

to achieve appreciable thermionic emission. The table also gives the comparative wattages in order to achieve appreciable thermionic emission with my improved rapid start lamps. Each value is expressed in watts and also as a percentage of the nominal lamp watts per foot of lamp.

Nominal lamp rating	Nominal length per foot	Lamp watts per foot	Switch start lamps				Rapid start lamps	
			Wattage for production of localized discharges		Wattage for achieving thermionic emission		Wattage for achieving thermionic emission	
			Watts	Percent of lamp watts per foot	Watts	Percent of lamp watts per foot	Watts	Percent of lamp watts per foot
20	2	10	5.1	51	2.45	25	1.3	13
40	4	10	6.4	64	2.8	28	1.3	13
85	5	17	15.8	93	7.7	45	3.0	18
100	5	20	15.8	79	7.7	38	3.0	15

It will be seen from the above table that the preheating wattages required to achieve appreciable thermionic emission with my improved "rapid start" lamps are all less than 20% of the lamp wattage per foot, while obtaining the lower voltage starting and the long life with high maintenance, that is, high lumens per watt throughout life. Conversely, present commercial switch-start lamps would all require more than 20%, and long life and high maintenance would not be achieved. In general, the 20% figure appears to be the maximum that can be tolerated, consistently with the above criteria, in order to allow the preheating wattage to waste during normal operation and yet maintain an overall economic efficiency for "rapid start" lamps equivalent to that of switch-start lamps, the former being operated per my "rapid start" method, and the latter per the switch-start method. It will be realized that the wattages necessary for achieving thermionic emission and which are given in the above table are those necessary for achieving the sudden drop in starting voltage, as illustrated in curves 22 through 26 of Fig. 2, within the time limits which have been mentioned in connection therewith, namely approximately ½ second. It will also be realized that, by reference to those curves, my "rapid start" lamps reach the point of sudden lowering of starting voltage, under conditions of potential gradient accentuation, with values of preheating wattage less than 20% of the lamp wattage per foot, whereas present commercial lamps require substantially more.

Although the additional starting aid which has been illustrated in Fig. 4 is a hydrophobic coating on the envelopes of the lamps which operates in conjunction with a grounded fixture, it will be understood that a conductive stripe or a conductive coating on the lamps may equally well be used. The matter of choice between the different starting aids is one of economic considerations and manufacturing facilities and any of these systems may be used in accordance with my invention.

4. *New electrode structure*

According to a further aspect of my invention, I have found that the different requirements of a cathode at starting and during operation may be disassociated, so to speak, and a more efficient and economical cathode provided by designing a portion thereof specifically for minimum power consumption in starting and another portion specifically for ability to withstand the rated discharge current during operation. It will be realized that a cathode of this type lends itself exceedingly well to incorporation in my improved lamp constructions for operation in accordance with the "rapid start" method because of the fact that the cathode heating current remains on during operation of these lamps. Although the lamp construction with a cathode reduced in size and similar to that described in the Aicher patent are entirely satisfactory, especially in the larger sizes such as the 40 watt lamps, it is nonetheless desirable to reduce the wattage dissipated in the filaments to lower values whenever economically feasible. It will also be understood that this is even more desirable in the case of low wattage lamps, wherein, for a given electrode wattage dissipation, the ratio of watts wasted in the electrodes to watts consumed by the lamp for illuminating purposes unavoidably increases. In accordance with this aspect of my invention therefore, I provide a cathode wherein a portion or element having a relatively low thermal capacity is heated for starting the lamp, and another portion or element carrying a relatively large amount of activated electron emitting material is utilized for supporting the arc during normal operation.

Referring to Fig. 5, the assembly **50** illustrates a preferred form of cathode in accordance with this aspect of my invention. This cathode bears some resemblance to that described in U. S. Patent 2,306,925—Aicher but the proportions of the turns and of the wire sizes as between the overwind convolutions and the main turns are quite different and are made specifically so for a different purpose. I shall accordingly describe this cathode in detail and also explain how it may be manufactured.

Referring to Figs. 6 and 7 which illustrate early stages in the manufacture of the cathode structure of Fig. 5, the first step is the making of a composite mandrel **51** consisting of two wires **52** and **53** laid longitudinally side by side. Wire **52** consists of 1.5 mil round tungsten wire and wire **53** consists of 10 mil round molybdenum wire. On this composite mandrel, are wound three parallel strands **54** of 1.5 mil tungsten wire. As here shown, the wires **54** are first wound on the composite mandrel **51** to form a series of slightly elongated or oval convolutions. The wires **52** and **53** are made of different metals such that one is not attacked by a reagent that may be used to dissolve and remove the other.

Referring to Fig. 5, the composite mandrel **51** with its overwind of triple 1.5 mil tungsten wire is coiled upon itself to form a helix **55**. In practice, the helix may be formed by wrapping the composite mandrel **51** with its overwind wires around a 45 mil steel mandrel which latter mandrel is subsequently withdrawn. The molybdenum wires **53** in the composite mandrel may then be removed by placing the helix in a mixture of nitric and sulphuric acid. This mixture attacks molybdenum but does not affect tungsten, so that the final result is the coil or helix **55** of which the primary turns are constituted by principal tungsten wire **52** with the three parallel tungsten strands **54** wrapped around as loose overwind convolutions.

Helix **55** may now be mounted on a pair of lead wires **56—56'** which in turn are mounted on a suitable glass stem in order to constitute a cathode structure **50**. During the lamp manufacture, helix **55** is coated with activating materials such as barium and strontium carbonates and these are afterwards decomposed to their oxides by the usual procedures. In practice, the activating materials coat both the principal wire **52** and the overwind wires **54** and both become overlaid with the material. The decomposition of the carbonates into the oxides for activating the cathodes may be achieved by applying a suitable voltage across the lead wires **56—56'**; since the resistance of the heating portion constituted by wire **52** is lower than that of the overwind, a larger current will flow through the principal conductor **52**. However the heating or principal wire **52** is in reasonably close proximity to the overwind wires so that it will impart a share of its heat to the activating material carried on the overwind. Although I have described helix **55** in the improved cathode **50** of Fig. 5 as being constituted by a principal conductor **52** of 1.5 mil tungsten with an overwind of three parallel 1.5 mil tungsten wires **54**, it will

be apparent that variations therefrom may be made. For instance a flat ribbon wire may be utilized instead of three fine wires, for the overwind.

It will be observed that the cathode structure of Fig. 5 differs from those described in the Aicher patent by the complete inversion of the relative sizes of the principal and of the overwind wires. The Aicher cathodes are intended to start instantly at a low temperature and to heat up rapidly or at least to have the activated material thereon heat up rapidly in order to avoid sputtering at starting. For this reason, the overwind wires in the Aicher cathode are very fine in order to have a low thermal capacity and they carry only a minute fraction of the discharge current.

On the other hand, in my improved cathode as illustrated in Fig. 5, the overwind convolutions are intended to heat up gradually only, but once they have heated up, they must carry the major share of the discharge current. Accordingly, my cathode is characterized by a much greater current carrying capacity in the overwind convolutions. My cathode is characterized also by the provision of the overwind convolutions with a very large winding diameter so that they fit quite loosely on the inner or principal wire. As a practical matter, the overwind convolutions are so loose on the principal wire that they have a tendency to bunch together in groups of close strands depending upon the number fed on the mandrel at one time, as the three shown in Fig. 5. The use of a large winding diameter insures that the main portion of the convolutions is located at a relatively much larger spacing from the principal wire than in the Aicher cathode. These features permit raising the temperature of the principal wire by means of a very small current flowing therethrough without, at the same time, raising the temperature of the whole mass of the overwind convolutions and of the activated material to the same degree.

Referring to Fig. 8, there is shown a fluorescent lamp **60** provided with my improved type of cathode and connected into a starting and operating circuit in accordance with my improved "rapid start" method of operation. The fluorescent lamp **60** comprises a glass envelope containing a rare gas such as argon at a low pressure of a few millimeters in combination with the usual small quantity of mercury. Sealed into opposite ends of the envelope are a pair of thermionic cathodes **50** and **50'** as illustrated in Fig. 5.

The discharge path of the lamp is included in a circuit **61—61'** which is connected across the output terminals of a high leakage reactance transformer **62**. The transformer comprises a primary winding **63** adapted to be connected to a source of alternating current such as the usual 115 volt 60 cycle supply mains, at the terminals **64—64'**. The output circuit of the transformer is constituted by one side of primary winding **63** and by one side of a secondary winding **65** which is loosely coupled to the primary and connected to its high side. A pair of low voltage secondary windings **66** and **66'** are connected to cathodes **50** and **05'**, respectively for supplying heating current to them.

Located longitudinally along the outer wall of the glass envelope of the lamp is an auxiliary starting aid in the form of a stripe **67** which may be either a thin strip of metal such as aluminum or a conductive coating on the glass as described heretofore. In this particular circuit, I have shown the stripe **67** as being connected, in series with a limiting resistance **68**, to one side of an auxiliary winding **69** on transformer **62**. The other side of the auxiliary winding is connected to either side of the operating circuit **61—61'**, the connection being made to **61'** in the drawing.

In accordance with my improved method of operation, transformer **62** is designed so that windings **66** and **66'** provide just sufficient current to the cathodes to heat their principal wire **52**, that is, the heating portion within the cathodes, to a temperature within the range from 550° to 900° C. The current supplied to the cathodes is not however sufficient to produce localized regions of ionization within the lamp, nor will it provide enough heat to raise the activated overwind portion of the cathode to its normal electron emitting temperature. The principal conductor in the cathodes is heated just sufficiently to permit the activated material immediately in contact with it to emit electrons.

The starting aid is utilized for accentuating the potential gradient in the immediate vicinity of the electrodes, and the increase in required starting voltage due to the lower electrode temperature is offset thereby. Accordingly, with the assistance of the potential impressed on the stripe **67**, a discharge starts within the lamp between the principal wires of the cathodes that is between the inner wire **52** of the two electrodes. In order to strike the inner wire, the discharge must pass between the convolutions of the overwind so that the overwind is heated and gradually reaches electron emission temperature. When this temperature is reached, due to the favored position of the overwind whereby the arc length in the tube between the overwind wires is less than the arc length between the inner or principal wires in the cathodes, the arc shifts from the principal wire to the activated material on the overwind and forms a hot spot thereon. Thereafter, the activated material on the overwind serves as the major source of electrons for maintaining the arc. After the arc is started, the discharge current flowing through the leakage reactance of secondary winding **65** produces a voltage drop thereacross which reduces the voltage applied to the lamp and counteracts its negative resistance characteristic.

It will be understood of course that with these improved cathodes it is even less necessary to discontinue the heating current during normal operation than it is with the lamp structure illustrated in Fig. 4. In an actual construction of a lamp provided with these improved cathodes, I have found that the required wattage for heating the principal wire **52** of the cathodes for starting is less than 1 watt and may be entirely disregarded in practice. However, where the type of circuit utilized permits it, it may be advantageous to cause a reduction in heating current through the cathodes in the same proportion as the reduction between the starting voltage applied across the lamp electrodes and the normal operating voltage. For instance, with the common lower voltage fluorescent lamp, such as the 15 and 20 watt sizes, where a simple series inductance is used as the ballasting device, it is naturally preferable to connect the primary of the electrode heating transformer on the lamp side of the series inductance rather than on the line supply side. With such a circuit, it is entirely feasible to obtain a reduction in heating energy or wattage in a ratio of approximately 2 to 1 so that the wattage loss during operation is less than ½ watt per cathode. However, with these improved cathodes, while such a provision may be advantageous, it is not necessary, as with practically all common sizes of lamps, even the smaller ones, the cathode heating energy is so low that it may be allowed to continue during operation with very little decrease in efficiency of the lamp and circuit combination as a whole.

5. Improved electrodes of general applicability

The electrode of Fig. 3 which has been particularly described under heading **3** of this specification in connection with my improved "rapid start" lamps, has been found to have very definite advantages when incorporated into lamps for present commercial systems of operation, namely, the switch-start and instant-start systems. This unexpected result is particularly noticable when this electrode is incorporated into an instant start lamp, and it is all the more surprising in view of the fact that the electrode of Fig. 3 is essentially a modification of the

electrode described in Aicher Patent 2,306,925 which was specifically designed for, although not limited to, instant-start lamps. The modification consisted mainly in reducing the number of major turns from 9.5 to 3 as shown at **134** in Fig. 3. In addition, the legs or extensions of the three major turns were lengthened and this permitted mounting the electrodes on lead-in or support wires having the same general configuration as before. To summarize, the electrode of Fig. 3 has three major turns instead of 9.5; these three major turns plus the longer legs achieve substantially the same axial dimension as in the instant-start electrode; the total amount of tungsten wire is approximately half that of the prior Aicher electrode, and the amount of activating material is in roughly the same proportion.

From the above description, it would hardly be expected that an instant-start lamp comprising the electrode of Fig. 3 would have a life comparable to an instant-start lamp comprising the electrode of longer major coiling. However, such is actually the case, as is demonstrated in Fig. 12 showing the results of actual life tests conducted on two groups of instant-start lamps, the first group including the electrodes of Fig. 3 and the second group including the prior art electrodes. The two sets of lamps were operated under identical conditions on high voltage instant-start ballasts, that is ballasts which start the arc through the application of a high voltage across the electrodes and without any preheating thereof by current from some other source. Actual lamp failures are shown by the circled dots and X's for the first and second groups respectively; the results are plotted on standard arithmetic probability paper in accordance with conventional practice. It will be noted that curve **90** which represents the average life characteristic of lamps equipped with the electrode of Fig. 3, crosses the 100 percent nominal life level with only 26% lamp failure. On the other hand, curve **91** which represents the average life characteristic of lamps equipped with the prior art electrode, crosses the 100 percent nominal life level with 44% lamp failure. These results clearly establish that the electrode of Fig. 3, when incorporated into instant-start lamps, has a life at least equal to, and in this particular instance, somewhat longer than that of standard instant-start lamps comprising the prior art electrode. This result is all the more startling when it is recalled that the electrode of Fig. 3 utilizes only half the amount of tungsten wire that the prior art electrode does.

I believe that this unexpected result is due to the entirely different ratio of minor turns contained in the major coil to the total number of minor turns in the electrode of Fig. 3, as contrasted with the corresponding ratio for the prior art electrodes such as the Aicher electrode. I wish it to be understood that I offer the following explanation by way of theory only; however it seems amply supported by a series of tests which I have conducted in connection with it. Referring to Figs. 9*a* and *b*, which illustrate respectively, in diagrammatic form, electrode **30** of Fig. 3 and the Aicher electrode particularly described in Patent 2,306,925, page 5, column 1, line 66 to column 2, line 26, the notations C and L designate respectively the major coil and the leg portions of the electrode which are coated with activated electron emitting material. It will be understood that both the major coil and the leg portions are made up of the minor turns **37** of which an expanded view is shown in Fig. 3*a*, and that these minor turns are made up of the tungsten wire **35** with an overwind about it constituted by the tungsten wire **36**, the whole being coated with activated electron emitting material such as alkaline earth oxides. The proportion of the minor turns in the major coil portion of electrode **30** is approximately 50 percent of the total contained in the electrode. In other words, letting N stand for the number of minor turns in the portion of the electrode indicated by subscript, the wire or minor turn ratio

$$\frac{Nc}{Nc+N_{L_1}+N_{L_2}}$$

is approximately 60%, whereas in the electrode **30'** corresponding to the prior patent, the ratio is approximately 99%. The ratio of emission mix as between the two portions is generally similar, being 50% for electrode **30** and 99% for the Aicher electrode; it is not identical with the wire ratio because care must be taken to prevent the emission mix from running out onto the support wires **32, 32'** during the manufacture of the lamp. If the emission mix, comprising mainly alkaline earth carbonates, is allowed to run out onto the support wires, it is practically impossible to degasify the lamp because the emission mix on the support wire cannot be heated up enough to reduce the carbonates to the oxides.

I have constructed other lamps wherein the number of major turns in the coiled portion C has been reduced to four turns and also to two turns, the ratios for these proportions being 68% and 48% respectively. In both cases, the life was comparable to that obtained with the prior art cathodes. However, when the number of turns is reduced to zero, that is when the cathode is merely a straight length of minor turns mounted between the support wires, the life test results show up very poorly.

These results appear to follow from the theoretical considerations which were discussed under heading 4 of this specification, namely, that the requirements of a cathode at starting and during operation are different. Proceeding from that premise, I reason that the cathodes must satisfy two conditions in order to achieve maximum life: firstly, they must heat up properly on the available starting energy; secondly, during normal operation, the arc must stabilize, that is, form a hot spot, on a portion which is at the optimum temperature for maximum length of life. It would appear that a cathode which has a practically uniform temperature characteristic cannot effectively satisfy both conditions. The electrodes in accordance with the prior art have always had some leg portion for fastening onto the leads. But the leg portions were generally considered for this mechanical reason only, and their electrical characteristics appear to have been discounted or ignored. I now believe that the leg section can be that portion of the cathode which best satisfies the operating conditions, whereas the major coil portion can best satisfy the starting conditions. Since the minor turns are substantially uniformly distributed throughout the major coil and leg portions, the heat generated by current per unit length of minor turn is substantially the same throughout both portions. However since the turns are condensed and have less heat dissipating capacity in the coil portion, that portion heats up more quickly and also attains a higher temperature than the leg portion. Accordingly, the arc first strikes on the coil portion because it is the first to achieve electron emitting temperature. Thereafter, the arc transfers to one of the leg sections and stabilizes on the point having sufficient electron emitting material which is located closest to the active current-carrying lead wire. This latter effect is automatic because the resistive drop through the electrode due to the discharge current will cause the arc to shift to a point of higher potential which point is obviously closest to the lead wire.

As long as the arc can start in the coil portion and operate on the leg portion, it will do so. Of course, after the emissive material on the leg portion has been thermally evaporated, the arm will strike in the coil portion and continue to operate on that portion. However the temperature of the coil portion is in excess of the optimum, so that the emissive material evaporates much more quickly under those conditions. It would thus appear that prior art electrodes as dimensioned did not have the unique arrangement of wire and emissive material as between the coil portion and the leg portions, in order to secure

maximum life. I have found that maximum life on a standard 3-hour per start test cycle is obtained with two to four turns in the major coil. Generally, maximum life is attained when the major coil or starting portion contains less than 70 percent of the total number of minor turns and roughly the same proportion of emission material, instead of upwards of 85% as has been utilized up to the present.

My explanation above appears to be confirmed by the fact that when the number of turns of the major coil is reduced to zero, the lamp has a very short life. This appears to be due to the fact that the cathode suffers great damage at starting because no portion thereof is able to heat up quickly enough on the available energy. On the other hand making such a cathode fine enough so that it will heat up quickly on the available starting energy does not offer a solution; under such conditions poor results are still obtained, apparently because the cathode spot temperature rises above the optimum for maximum life.

Thus by proportioning the length of the leg portions to the major coil portion, it is possible to realize a much superior utilization of cathode material than has been achieved heretofore. The ratio of tungsten wire or minor turns in the major coil portion with respect to the total will depend on the type of service for which the lamp is intended. The standard 3-hour per start test cycle corresponds quite closely to the number of starts per hours of life experienced with lamps in industrial service. On the other hand the half hour cycle test corresponds more closely to the type of service encountered in home use wherein a lamp is more likely to be used for shorter periods of time at more frequent intervals. In general, it appears that a ratio between 40 and 70 percent achieves a good compromise for both types of service.

It will be realized that these results are fully in accord with the other aspects of my invention and more especially with the theoretical considerations discussed under heading 4 of this specification. The new electrode structure described under that heading and illustrated in Fig. 5 also achieves the necessary compromise for maximum life, namely a portion which heats up quickly for starting purposes and another portion which runs at a cooler temperature for supporting the arc during normal operation.

For obtaining maximum life from the cathode **30** of Fig. 3, it appears desirable to connect both lead-in or support wires together to the source of potential. This is illustrated in Fig. 10*a* showing a single end section of a low pressure discharge lamp **70** whereof both lead-in wires **32, 32'** of the electrode **30** are connected to terminal **71** constituting one side of a voltage source. With these connections, the arc strikes initially on the major coil portion C as indicated by the arrow **72**, and thereafter can transfer to either leg portion L_1 or L_2 as indicated by the arrows **73, 74**. Thus full utilization is made of both leg portions for supporting the arc during normal operation. On the other hand, if only one of the lead-in wires is connected to the voltage source, for instance lead-in wire **32** in lamp **70'** of Fig. 10*b*, the arc will start in the coil portion C as indicated by the arrow **72** and thereafter will shift to the leg portion L_1 as indicated by the arrow **73**. The arc will not shift to the leg portion L_2 until all the emissive material has been exhausted in portions L_1 and C; of course at this stage, since the starting portion C is exhausted, the lamp will lose a large quantity of emissive material during the starting period so that it will quickly reach the end of its life and the leg portion L_2 will not be utilized economically.

A compromise structure for the case when only one side of the electrode is connected to the voltage source is illustrated in Fig. 10*c*. The low pressure discharge lamp **75** shown therein is connected in a conventional switch-start circuit, one side of each electrode **76** being connected through its lead wire **32** across a voltage source **77** in series with a ballasting inductance **78**. The other side of each electrode is connected, through its lead wire **32'**, in a shunt circuit including the usual thermal switch **79**. In order to achieve maximum utilization of the cathode material, the leg portions of the cathodes **76** are made unsymmetrical, the leg portion L_1 being approximately twice as long as before, while leg portion L_2 is made as short as possible consistant with the mechanical requirements of receiving support from the lead-in wire **32'**. With this arrangement the arc will strike on the major coil portion C as indicated by the arrows **72**, and will thereupon shift to the long leg portion L_1 for normal operation, as indicated by the arrows **73**. Since the leg portion L_2 cannot be effectively utilized, it is made as short as possible and the material which would otherwise have gone into it is thus incorporated into the leg portion L_1 and effectively utilized therein. It will be understood of course that such a construction, in order to be practical, requires the use of a polarized socket and base pins in order to insure that the proper connections are made to the electrodes when the lamp is located in a fixture.

In general, the most practical form of electrode is one wherein the leg portions extend straight out from the major coil portion and parallel to its axis, as illustrated in Fig. 3 and in Fig. 9*a*. This type of coil lends itself most readily to mounting by automatic machinery. However other electrode configurations may be utilized, and in general the position or direction of the legs with respect to the axis of the major coil portion does not seem to be of great importance. In Fig. 11*a*, there is shown an electrode **80** wherein the leg portions are at 45° to the axis of the major coil. In Fig. 11*b*, electrode **81** has its leg portions transverse or at right angles to the axis of the major coil. In Fig. 11*c*, electrode **82** has its leg portions parallel to the axis of the major coil but the electrode itself is mounted for axial positioning of the filament within a tubular lamp. Any of these electrode configurations may be surrounded by a shield, if desired, to prevent end darkening of the envelope. In general it appears that all the configurations illustrated or variations therefrom may be utilized successfully with the long leg features in accordance with my invention.

The small size filamentary electrodes in accordance with the invention are basically of low voltage design and normally will start without the production of end glow or discharges, even when used in conventional switch-start circuits. However under certain extreme conditions, as under maximum line voltage with some commercial lead-lag ballasts, the preheating current to the electrode may become excessive. This is particularly apt to occur in the lag lamp of such a ballast should the lead lamp be removed or for some other reason be inoperative. This condition may be aggravated by a starting switch which is slow in reopening, and may result in end darkening of the lamp by the evaporation of emissive material from the overheated filament. With prior art electrodes which were of basically higher voltage design, the above described condition did not occur because end glow was produced and part of the preheating current was shunted around the filament through the glow and thus did not operate to heat the filament. The small size low voltage electrodes in accordance with my invention may be protected under these conditions by means of an anode or shield structure so that it is not necessary to make the filament larger. The anode may be merely a conductive element connected to one end of the filament and having a portion extending into proximity to the other end thereof. When such an anode or shield structure is provided, an end glow of sufficient intensity may be produced, under conditions of excessive preheating currents, which will suffice to protect the filament under those circumstances.

A modified electrode assembly incorporating small size filamentary electrodes and adapted to meet conditions of excessive preheating is illustrated at **100** in Fig. 13. It will be understood that this assembly is designed speci-

fically for switch-start operation with a view to avoiding the above mentioned difficulties of thermal evaporation and end darkening on excessive preheating currents. The electrode in general is similar to electrode **30** of Fig. 3 and comprises the lead-in or support wires **32, 32'**, whereof the ends are formed into the transversely turned hooks **132, 132'**. The hooks are pinched closed upon the ends of the filament **34** which they support. In addition, the free ends of the hooks are extended into parallel elements **232, 232'** which are bent back on either side of the filament parallel to its major axis.

The electrodes, according to a broad aspect of my invention, are basically low voltage electrodes and do not require the production of an end glow across the terminals in normal operation. However, in order to increase the field of use and to give flexibility of use to lamps incorporating my invention and to permit their efficient operation in the now conventional type circuits and ballasts providing much higher filament or electrode voltages, the above-described anodes **232, 232'** may be incorporated as part of the electrode structure in order to provide a discharge path in parallel with the filament of the electrode so that the filament is not required to dissipate all of the starting energy supplied by the ballast.

The parallel elements **232, 232'** operate as anodes during the half cycle when the electrode is positive during operation. This effect of the anode elements is well known to the prior art. In addition, during the starting cycle on switch-start operation, if the preheating current is excessive, a glow may occur across the ends of the filament. By reason of the proximity of the ends of the parallel elements to the opposite potential ends of the filament, the formation of the glow or discharge is facilitated. The discharges in question are indicated by the dotted lines at **101, 101'** in the drawing. As a result, a certain portion of the preheating current is shunted around the filament through the end discharges to the anode elements, and less preheating current actually flows through the filament which accordingly runs cooler. End darkening of the lamp through excessive thermal evaporation at starting is thus avoided. It will be realized of course that a shield surrounding the filament may also be utilized as an anodes element, and will accomplish like results in preventing end-darkening even more effectively, both by reducing the filament temperature on abnormally high preheating currents and also by trapping evaporating emissive material.

I have found that anode elements **232, 232'** are desirable on small size electrodes for switch-start operation in order to meet operating conditions imposed by prior art ballasts and fixtures. They appear to be superfluous on instant-start or rapid-start operation.

6. *Lamp life and general considerations*

With the "rapid start" mode of operation in accordance with my invention, I have discovered a remarkable lengthening in the life of fluorescent lamps over that of similar lamps operated in the instant-start manner well known to the art. Lamps equipped with cathodes exactly as described in the Aicher patent and operated in accordance with the soft start method will give a cathode and lamp life much in excess of that obtainable in instant-start operation. It will thus be seen that the "rapid start" method of operation which I have discovered can be applied advantageously to discharge lamps in general, although the maximum benefits from the application of the method will naturally be derived from its use in conjunction with my improved types of lamp which make it economical to allow the heating current to the electrodes to continue during normal operation.

Comparing the life of lamps operated in accordance with the switch start method as against those operated in accordance with my "rapid start" method, I have found that the average life with the "rapid start" method is generally as long and in some cases is longer. However, as between the improved fluorescent lamps in accordance with my invention such as I have described by reference to Figs. 4 and 8 and containing cathodes of the types illustrated in Figs. 3 and 5, and the usual switch-start fluorescent lamp, these "rapid start" lamps operated in accordance with the "rapid start" method in practically all cases have a considerably longer life.

I believe that the explanation for the longer life obtainable by the "rapid start" method is as follows, although it will be understood that I offer this explanation by way of theory only. The shorter lamp life with prior art systems appears to be due to the fact that whenever a high voltage or a shock impulse is used to start an arc between cold cathodes, the effect might be likened to "brute force" starting, and some sputtering of the cathodes occurs which causes the material to be deposited on the ends of the glass envelope, producing what is commonly known as end darkening. Needless to say, this sputtering produces deterioration of the cathodes and a corresponding shortening of lamp life. With my new method of starting however, the discharge passes through a gradual transition from a glow originally produced by the capacitive effect of the starting aid, then into a gow between opposite electrodes, which gow gradually increases in intensity and finally transfers into a normal arc discharge in mercury. Thus, there is no shock or impulse starting of an arc on cold electron emitting material and the amount of sputtering which occurs at starting is reduced to insignificance. Accordingly, the permissible number of starts for cathodes containing the same amount of activated material is many times greater with my "rapid start" method of operation than with the instant-start method where the cathodes are cold.

It will have been realized from the foregoing that my "rapid start" method of operation permits a great simplification in the design of auxiliary equipment for fluorescent lamps. Since there is now no need for glow switches to open the filament heating circuits or for a neutralizing winding to reduce the filament heating voltage, the equipment need only comprise a ballast furnishing low voltage, and, if desired, potential to the auxiliary starting aid. Moreover, the heating current required by the cathodes is quite small so that the size and capacity of the transformer heating winding may be reduced accordingly.

While certain specific lamp and cathode constructions have been shown and described as the preferred means for carrying out the method of my invention, it will be realized that my improved method can be applied to existing types of fluorescent lamps on the market. And as for the lamps and cathode structures, it will also be realized that various modifications may be made in their details without departing from the true spirit and scope of the invention. Thus the overall sizes of both types of cathodes which I have described may evidently be varied to suit the size and rating of the discharge device into which they are to be incorporated. Needless to say any type of phosphor or fluorescent coating may be applied to the lamp to provide different light emitting properties. The appended claims are intended to cover any modifications in either the method, or the lamp, or cathode structures, coming within the true spirit and scope of the invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. An electric discharge device of the positive column type, comprising a closed envelope, an inert gas at a pressure of a few millimeters and a small quantity of mercury contained in said envelope, and a pair of filamentary electrodes sealed into the ends ot said envelope, said electrodes comprising a heating element in the form of a coil of wire having connections to the exterior of said envelope, and an electron-emitting element of larger cross-sectional area than said heating element in the form of overwind convolutions of wire wound axially on and fitting loosely over the turns of said coil, and having connections to the ends

thereof, said overwind convolutions being coated with activated electron-emitting material, and said overwind convolutions having a diameter many times larger than the diameter of said wires and having a relatively high winding pitch in order to establish said electron-emitting element in relatively loose thermal contact with said heating element.

2. An electric discharge device of the positive column type, comprising a closed envelope; an inert gas at a pressure of a few millimeters and a small quantity of mercury contained in said envelope, and a pair of filamentary electrodes sealed into the ends of said envelope, each of said electrodes comprising a heating element in the form of a coil of a first wire having connections to the exterior of said envelope, and a main electron-emitting element of larger cross-sectional area than said heating element in the form of overwind convolutions of a second wire wound axially on and fitting loosely over said first wire, both said elements being coated with activated electron-emitting material, said overwind convolutions having a diameter many times larger than the diameter of said first wire in order to permit the developing of a temperature difference between said elements so that the application of heating current to said heating element will permit it to attain a temperature much higher than that simultaneously attained by said main electron-emitting element.

3. An electric discharge device of the positive column type, comprising a closed envelope, an inert gas at a pressure of a few millimeters and a small quantity of mercury contained in said envelope, and a pair of filamentary electrodes sealed into the ends of said envelope, said electrodes comprising a heating element in the form of a coil of a conductor having its ends brought out to the exterior of said envelope, and an electro-emitting element of larger cross-sectional area than said heating element in the form of overwind convolutions of wire wound axially over and fitting loosely on said conductor, said overwind convolutions being coated and overlaid with activated electron-emitting material, said overwind convolutions having a diameter many times larger than the diameter of said conductor in order to establish said electron-emitting element in relatively loose thermal contact with said heating element so as to permit raising the temperature of said heating element to electron emission with a relatively small fraction of the energy which would otherwise be required to heat the whole electrode to an electron-emitting temperature.

4. An electrode for a discharge device comprising a principal refractory conductor of predetermined cross-section, a secondary refractory conductor of larger cross-section coiled around said principal conductor in overwind convolutions having a diameter many times larger than the diameters of said conductors in order to establish said secondary conductor in relatively loose thermal contact with said principal conductor, and a coating of activated electron-emitting material held in said convolutions.

5. An electrode for a discharge device comprising a principal refractory metal wire of predetermined cross-section, a plurality of secondary refractory metal wires having a larger total cross-section and coiled around said principal wire in overwind convolutions having a diameter many times larger than the diameter of said principal wire and with a relatively high winding pitch in order to establish said secondary wires in relatively loose thermal contact with said principal wire, and a coating of activated electron-emitting material held in said convolutions.

6. A cathode structure for an arc discharge device comprising a filament defining two dislaced regions, said filament comprising a few closely grouped major turns of minor coiling defining one region of heat localization for initiating an arc discharge, and a relatively long section of minor coiling defining another region for maintaining the discharge after its initiation, and activating material filling said minor coiling in both said regions.

7. A low pressure positive column discharge device comprising an elongated envelope having a pair of electrodes sealed into opposite ends thereof, said envelope containing a starting gas at a pressure of a few millimeters and a small quantity of mercury, each of said electrodes comprising a coiled-coil filament defining two axially displaced regions, one region of heat localization for initiating the arc discharge and the other region for maintaining the discharge after its initiation, said filament comprising a few closely grouped major turns of minor coiling centrally located between relatively long extensions of minor coiling, substantially all of said minor coiling in both said regions being filled with activating material.

8. A cathode structure for an arc discharge device comprising a filament defining two displaced regions, one region of heat localization for initiating the arc discharge and the other region for maintaining the discharge after its initiation, said filament comprising a major turn portion of minor coiling located adjacent to at least one relatively long linear extension of minor coiling, said minor coiling in both said regions being substantially filled with activated electron emitting material, and not more than 70 percent of the total of said minor coiling being contained in said major turn portion.

9. A low pressure positive column discharge device comprising an elongated envelope having a pair of electrodes sealed into opposite ends thereof, said envelope containing a starting gas at a pressure of a few millimeters and a small quantity of mercury, each of said electrodes comprising a filament defining two displaced regions, one region of heat localization for initiating the arc discharge and the other region for maintaining the discharge after its initiation, said filament comprising a major turn portion of minor coiling located adjacent to at least one relatively long linear extension of minor coiling, said minor coiling in both said regions being substantially filled with activated electron emitting material, and less than 70 percent of the total of said minor coiling being contained in said major turn portion.

10. In a thermionic cathode for an electric discharge device comprising a structure for supporting an arc discharge at two physically displaced regions thereon and each at a substantially different operating temperature in respect to the cyclic operation of initiating an arc discharge and maintaining it, a coiled-coil filament having activating material within the minor coiling thereof in both said regions and having a major coiled section comprising not less than two and not more than four secondary turns defining the region of heat localization for initiating an arc discharge and comprising in actual length, in respect to the overall minor coiling, not more than 70 percent thereof.

11. An electrode for a discharge device comprising a principal refractory conductor coiled into minor turns, an auxiliary refractory conductor wound around said principal conductor in loose fitting overwind convolutions, said minor turns with their overwind convolutions being substantially filled with activated electron emitting material and constituting a filament structure, lead-in wires supporting the ends of said filament structure, and a continuous portion not more than 70 percent of the total length of said filament structure located between said lead-in wires being coiled upon itself into major turns for defining a region of heat localization.

12. An electrode for a discharge device comprising a principal refractory conductor coiled into minor turns, an auxiliary refractory conductor wound around said principal conductor in loose fitting overwind convolutions, said minor turns with their overwind convolutions being substantially filled with activated electron emitting material and constituting a filament structure, lead-in wires supporting the ends of said filament structure, a continuous portion of said filament structure comprising 40 to 70 percent of the total length thereof located between said lead-in wires being coiled upon itself into major turns, and the remainder of said filament structure

extending directly from said major turns to said lead-in wires.

13. A low pressure positive column discharge device comprising an elongated envelope having a pair of electrodes sealed into opposite ends thereof, said envelope containing a starting gas at a pressure of a few millimeters and a small quantity of mercury, each of said electrodes comprising a principal refractory conductor coiled into minor turns, an auxiliary conductor wound around said principal conductor in loose fitting convolutions, said minor turns with their overwind convolutions being substantially filled with alkaline earth oxides and constituting a filament structure, lead-in wires supporting the ends of said filament structure within said envelope, a continuous portion of said filament structure comprising 40 to 70 percent of the total length thereof located between said lead-in wires being wound upon itself into major turns for defining an arc initiating region, and the remainder of said filament structure extending directly from said major turns to said lead-in wires and defining an arc sustaining region.

14. A cathode structure for an arc discharge device comprising a filament defining two displaced regions, said filament comprising a few closely grouped major turns of minor coiling defining one region of heat localization for initiating an arc discharge, and a relatively long section of minor coiling defining another region for maintaining the discharge after its initiation, activating material filling said minor coiling in both said regions, and at least one anode element connected to one end of said filament and having a portion extending into proximity to the other end of said filament.

15. An electrode structure for an electric discharge device comprising a principal refractory conductor coiled into minor turns, an auxiliary refractory conductor wound around said principal conductor in loose fitting overwind convolutions, said minor turns with their overwind being substantially filled with activated electron-emitting material and constituting a filament structure, lead-in wires supporting the ends of said filament structure, less than 70 percent of the total length of said filament structure located between said lead-in wires being coiled upon itself into a few closely grouped major turns for defining a region of heat localization for initiating an arc discharge, and a pair of anode elements each comprising the end of one of said lead-in wires projected on one side of said filament structure into proximity to the end of said filament structure supported by the other lead-in wire.

16. An electric discharge device comprising an elongated envelope containing an inert gas at a pressure of a few millimeters and a small quantity of mercury which, under normal operating conditions involving a given wattage consumption per foot length of said device, produces a vapor pressure not exceeding about 20 microns, a pair of electrodes mounted within said envelope at opposite ends, one at least of said electrodes being of the filamentary activated type, said one electrode having a physical configuration providing a low thermal loss characteristic which allows preheating to thermionic emission with energy less than 20 percent of said given wattage per foot, and having a low resistance across which preheating current sufficient for thermionic emission produces a voltage drop less than the ionization voltage of said vapor, and means additive to said envelope and extending the length thereof for effecting the accentuation of the potential gradient in the immediate vicinity of at least said one electrode when starting said device.

17. The device of claim 16, wherein both electrodes are like said one electrode defined therein.

18. The device of claim 16 wherein said one electrode is activated with alkaline-earth oxides and its physical configuration providing a low thermal loss characteristic allows preheating to thermionic emission at a temperature within the range from 500° to 900° C. with energy less than 20 percent of said given wattage.

19. The device of claim 16 wherein both electrodes are like said one electrode defined therein, and wherein the electrodes are activated with alkaline-earth oxides and their physical configuration providing a low thermal loss characteristic allows preheating to thermionic emission at a temperature within the range from 500° to 900° C. with energy less than 20 percent of said given wattage.

20. The device of claim 16 wherein said means additive to said envelope is a moisture film repellent coating preventing the lowering of the envelope wall resistance under humid atmospheric conditions.

21. The device of claim 16 wherein said means additive to said envelope is a conductive means applied to the envelope wall and extending the length thereof.

22. The device of claim 16 wherein the physical configuration of the electrode providing a low thermal loss characteristic allows preheating to thermionic emission in any event with energy less than 2 watts.

23. In combination, an electric discharge device comprising an elongated envelope containing an inert gas at a pressure of a few millimeters and a small quantity of mercury which under normal operating conditions involving a given wattage consumption per foot length of said device, produces a vapor pressure not exceeding about 20 microns, a pair of electrodes mounted within said envelope at opposite ends, one at least of said electrodes being of the filamentary activated type, said one electrode having a physical configuration providing a low thermal loss characteristic which allows preheating to thermionic emission with energy less than 20 percent of said given wattage per foot and having a low resistance across which preheating current sufficient for thermionic emission produces a voltage drop less than the ionization voltage of said vapor, and means additive to said envelope and extending the length thereof for effecting the accentuation of the potential gradient in the immediate vicinity of at least said one electrode when starting said device, and an operating circuit therefor including a main current source connected across said pair of electrodes for supporting a discharge through said vapor, an auxiliary current source connected across said one electrode for preheating it to thermionic emission and producing thereacross a voltage drop less than the ionization voltage of said vapor, and means cooperating with said additive means to apply a potential along the length of said envelope.

24. The combination of claim 23 wherein both electrodes are like said one electrode defined therein and including a pair of said auxiliary current sources, one for each electrode.

25. The combination of claim 23 wherein said one electrode is activated with alkaline-earth oxides and said auxiliary current source preheats said one electrode to a temperature within the range from 500° to 900° C.

26. The combination of claim 23 wherein said main current source applies across said electrodes an open-circuit voltage not substantially greater than that required to take advantage of the discontinuity in the starting voltage-electrode excitation characteristic occurring with the onset of thermionic emission when there is accentuation of the potential gradient in the immediate vicinity of said one electrode.

27. The combination of claim 23 wherein said auxiliary current source is adapted to maintain a substantial heating current through said one electrode during normal operation of said device.

28. The combination of claim 23 wherein said means additive to said envelope is a moisture film repellent coating preventing the lowering of the envelope wall resistance, and said means cooperating with said additive means includes a conducting fixture member extending in close proximity along the length of the envelope.

29. The combination of claim 23 where said means

additive to said envelope is a conductive means applied to the envelope wall and extending the length thereof, and said means cooperating with said additive means applies the potential directly to said conductive means.

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