

[54] PIEZOELECTRIC STARTER AND BALLAST FOR GASEOUS DISCHARGE LAMPS

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[51] Int. Cl. H01j 19/78

[58] Field of Search 310/9.8; 315/55, 315/246, 100 V; 331/158, 163, 185

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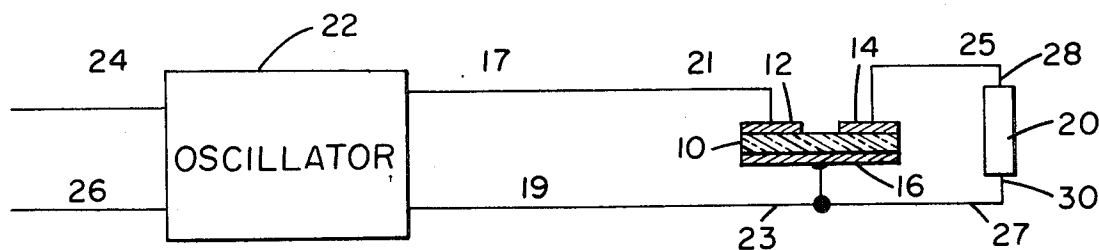
3,271,622	9/1966	Malagodi et al.	315/55 X
3,363,139	1/1968	Schiavone	315/55
3,421,109	1/1969	Wiggins et al.	310/9.8 X
3,453,458	7/1969	Curran et al.	310/9.8 X
3,495,105	2/1970	Shimano	310/9.8

Primary Examiner—Nathan Kaufman
Attorney—Edward E. Sachs

[57] ABSTRACT

A gaseous discharge lamp lighting system in which a monolithic piezoelectric element is energized by means of a frequency changer or oscillator to operate at a frequency corresponding to a predetermined extensional mode of mechanical resonance. The element is polarized to be responsive to the resonance and electroded for connection to the aforesaid power input source and for connection to electrodes of a lamp envelope containing ionizable gas.

6 Claims, 21 Drawing Figures



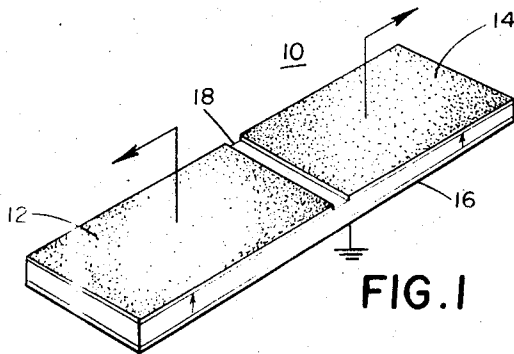


FIG. 1

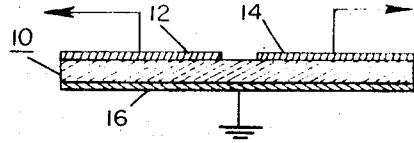


FIG. 1a

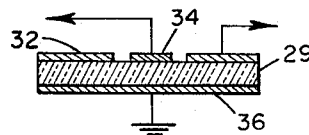


FIG. 2a

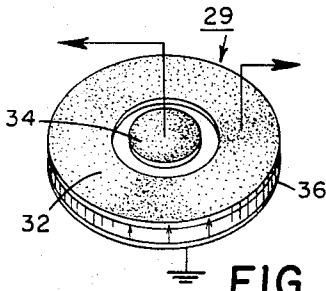


FIG. 2

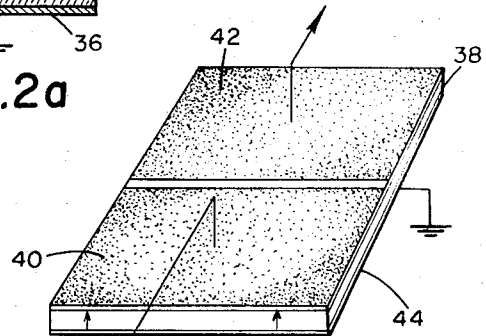


FIG. 3

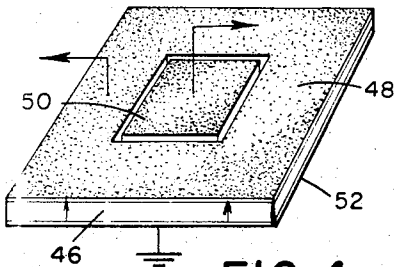


FIG. 4

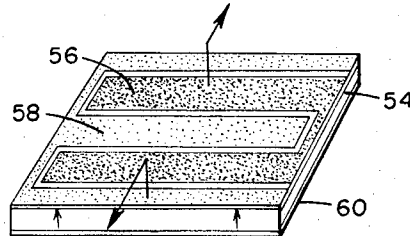


FIG. 5

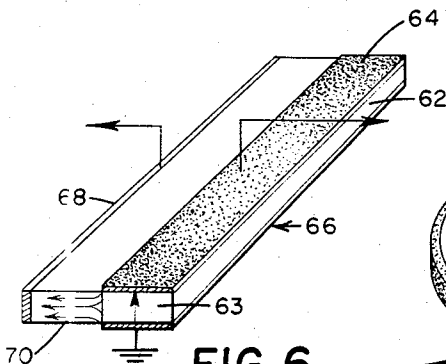


FIG. 6

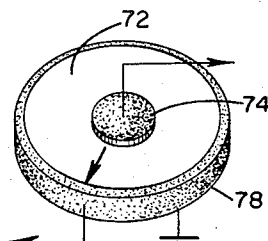


FIG. 7

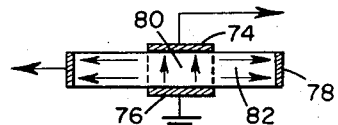


FIG. 7a

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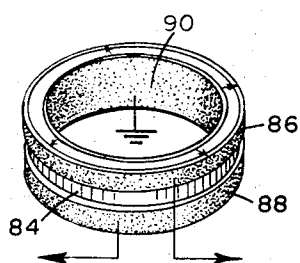


FIG. 8

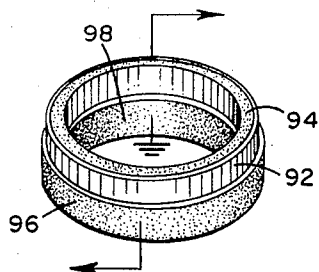


FIG. 9

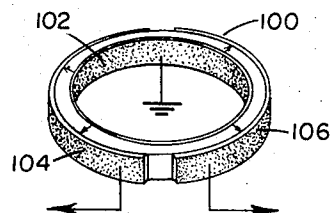


FIG. 10

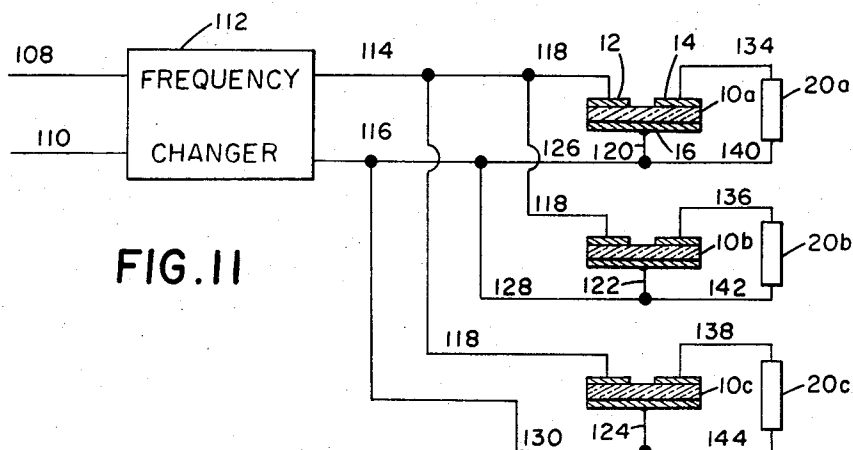


FIG. 11

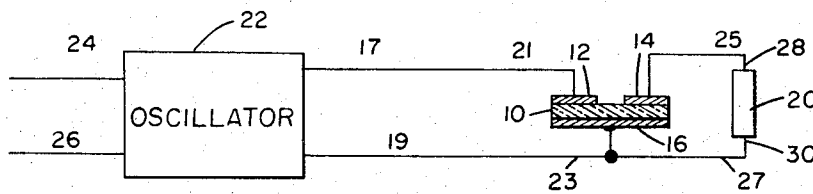


FIG. 12

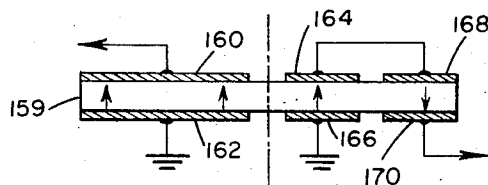


FIG. 16

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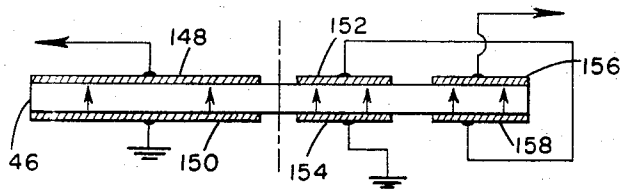


FIG. 15

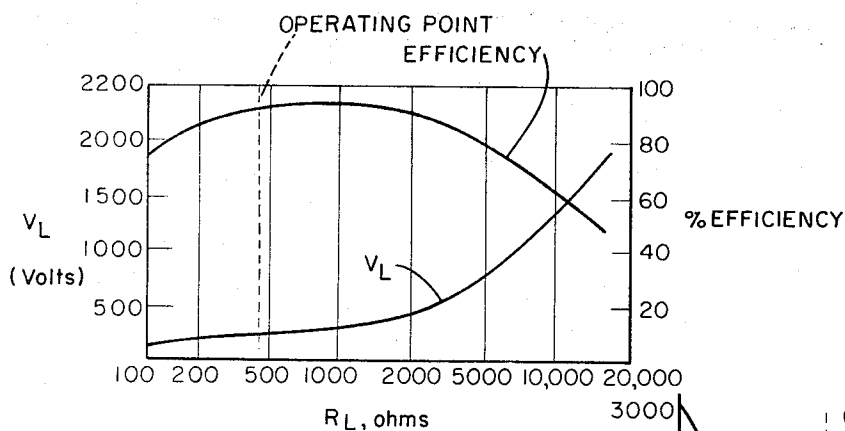


FIG. 13

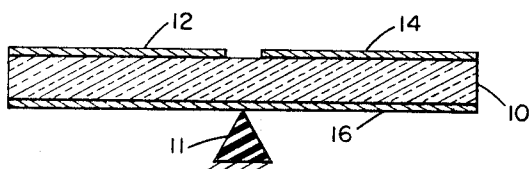


FIG. 1b

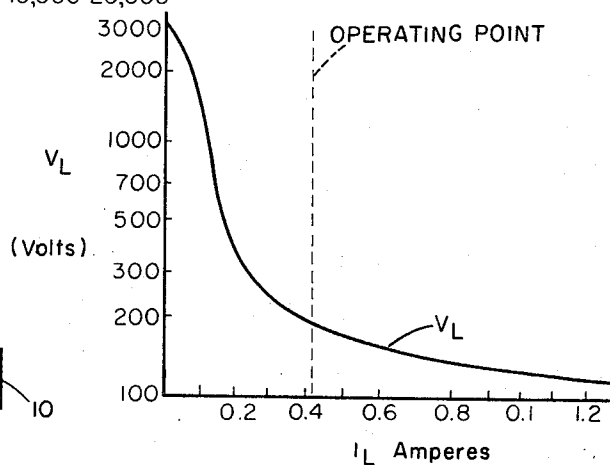


FIG. 14

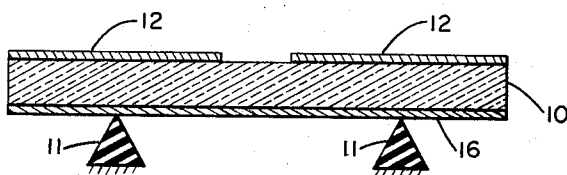


FIG. 1c

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PIEZOELECTRIC STARTER AND BALLAST FOR GASEOUS DISCHARGE LAMPS

This is a continuation, of U.S. Pat. application Ser. No. 865,412, filed Oct. 10, 1969 now abandoned.

The present invention relates generally to a lighting device and more particularly, to a gaseous discharge lamp and a piezoelectric device for starting and operating the lamp.

Piezoelectrically actuated and operated gaseous or arc discharge devices are already known in the art, and are discussed below in further detail. For a better understanding of the invention it should be understood that to start and operate a gaseous discharge lamp by means of a piezoelectric device, at high efficiency, the impedance of the piezoelectric device should be comparable to the ratio of voltage over current of the lamp. For example, for a lamp generally known as F96T12 (F = fluorescent, 96 = length of tube in inches, T12 = $12 \times \frac{1}{8}$ inch = diameter of tube), V/I is normally about 400 ohms. Therefore, for operating at 60 hertz a capacitance of at least 6 to 7μ is required. This necessitates a piezoelectrically responsive ceramic disc or plate about 10 mils thick which would provide approximately 250 square inches in area with a relative dielectric constant of 1,000. On the other hand, the thickness of the piezoelectric element should be at least 60 mils in order to provide the starting voltage for the gaseous discharge lamp without requiring too high a stress in the piezoelectric element. If the piezoelectric device be 60 mils thick, the required area would total about 1,500 square inches.

In the prior art, U. S. Pat. No. 3,271,622 discloses a piezoelectric device for the application herein under consideration. The device, in all of the disclosed embodiments, is composed of a plurality of individual ceramic elements which are bonded together and actuated for flexural mode vibration. Evidently this device is based upon the belief that the desired voltage can be obtained by a shift of the natural frequency. The patented invention does not appear to recognize that a change must occur in the reflected impedance in order to obtain the starting and ballast action. The prior art device is operated at 60 hertz and thus necessitates an extremely large area of ceramic material. Inasmuch as the device is intended to provide the starting voltage, a constraint is placed upon the thickness of the element which, in effect, makes it necessary to lengthen the piezoelectric elements unduly. It is believed that on the basis of the disclosure in the patent, ceramic plates of approximately 60 mils thick with a total area of at least 500 square inches are required for operation. The area could be reduced somewhat if one would be willing to sacrifice efficiency. Under those conditions it would perhaps be possible to arrive at a configuration having a total area in the vicinity of 300 square inches minimum. The resulting longitudinal dimension makes it virtually impractical to utilize such devices for the intended purpose.

In another approach of the prior art, there is shown in U. S. Pat. No. 3,363,139, a device which is composed of a driver element and a separate output element. When these two members are connected together considerable damping occurs in either the mechanical clamping or in the bonding. The device is operated from commercially supplied power lines at 117 volts which indicates that operation at 60 hertz is intended. The same shortcomings inherent in the above

described prior art device are also inherent herein because the dimensions of the ceramic elements are under exactly the same constraint. The device is not operated at resonance nor is a flexural mode used. Were the elements to be resonant at the conventional 60 hertz it would necessitate piezoelectric slabs about 30 meters long.

The present invention is based upon the recognition and theory that the piezoelectric element must be driven at or very close to the resonant frequency controlled by a major dimension. In order to reduce internal mechanical losses in the piezoelectric transformer and thus to improve the efficiency of the device, the present invention utilizes a monolithic piezoelectric element which is to say that only a single piece of ceramic material constitutes the entire piezoelectric transformer which is effective to start and to provide a ballast for the gaseous discharge lamp. A basic characteristic of the improved piezoelectric transformer resides in that an element with approximately equal input and output (geometrically similar) electrodes will provide a very high ratio of output to input voltage in the absence of current drain from the secondary electrodes, as is the case before a gaseous discharge lamp breaks down. Another major characteristic of the invention resides in that the secondary voltage decreases drastically once current begins to flow in the secondary circuit. This provides the feature required for the ballast or regulating function for the discharge lamp. When power at a frequency close to resonance is supplied to the primary electrode of the piezoelectric transformer a very high voltage is generated at the secondary electrode. This is effective to cause an arc to form in a fluorescent lamp or other gaseous discharge lamp. As soon as this current begins to flow, the secondary voltage drops. Changes in the primary voltage, once the lamp is operating, serve basically only to change the secondary current and cause very little change in the secondary voltage.

From the brief theoretical description of the present invention it will be appreciated that the present invention depends upon a very significant change in the voltage transformation ratio of the piezoelectric transformer with a change in the secondary load impedance. Prior art embodiments have either not utilized resonance in the piezoelectric element, in which case the peculiar attribute of the piezoelectric transformer mentioned above cannot be used, or there has been a failure to recognize or utilize this feature of the piezoelectric transformers.

It is therefore the primary object of this invention to provide a piezoelectrically actuated and operated gaseous discharge lamp in which the piezoelectric actuating device functions at a high degree of efficiency and has substantially reduced geometrical configuration.

It is a further object of this invention to provide a piezoelectrically actuated and operated gaseous discharge device in which a monolithic piezoelectric element operates at or very near a specific and predetermined mechanical resonance.

An aspect of the present invention resides in the provision of a gaseous discharge lighting system in which there is provided an envelope containing an ionizable gas, and a pair of electrodes within the envelope for establishing an electrical path through the gas. A piezoelectric device is effective to provide a relatively high starting voltage and a limitation upon the operating

current of the lamp once the arc is initiated. The device includes a monolithic piezoelectric element effective for operating at a frequency corresponding to a predetermined extensional mode of mechanical resonance; the element is oriented or polarized so as to be responsive to the resonance and has at least three physically separate electrodes, with at least two of these three or more electrodes being connected to an electrical power input source and at least two of the same three or more electrodes being connected to the above mentioned pair of electrodes within the envelope.

For a better understanding of the present invention, together with other and further objects thereof, reference is had to the following description taken in connection with the accompanying drawings, and its scope will be pointed out in the appended claims.

In the drawings:

FIG. 1 is a perspective view of a piezoelectric transformer in accordance with this invention and FIG. 1a is a longitudinal cross-section thereof;

FIGS. 1b and 1c are views similar to FIG. 1a and show two different ways of mounting the piezoelectric transformer;

FIGS. 2 to 10 are views of different geometrical configurations of the piezoelectric transformer with FIG. 2a being an axial cross-sectional view of FIG. 2, and FIG. 7a being an axial cross-sectional view of FIG. 7;

FIG. 11 is an electrical circuit diagram illustrating a system for operating a multiple of gaseous discharge lamps;

FIG. 12 is an electrical circuit diagram illustrating a system for operating a single gaseous discharge lamp;

FIGS. 13 and 14 are charts illustrating the efficiency and performance capability of the invention; and

FIGS. 15 and 16 are modifications of the device shown in FIG. 1 having a multiple of electrode pairs.

Turning now to the drawings, and specifically to FIGS. 1 and 1a thereof, there is shown a typical piezoelectric element 10 in accordance with this invention formed as a longitudinally extending plate. A typical element 10 has a length of 10 cm. (centimeters), width of 4 cm. and a thickness of 0.25 cm.

The piezoelectric element, or transformer 10, is composed, preferably, of material such as lead zirconate-titanate which includes as an additive or substitute for some of the lead, an alkaline earth metal such as barium, strontium or calcium. The piezoelectrically responsive material is preferably acceptordoped and includes in addition to the alkaline earth metal additive described above, additives such as iron, nickel or cobalt, or scandium.

It has been established that lead titanate zirconate compositions in which a small portion of a constituent element is replaced by an additive of lower valency, an acceptor, high amplitude dielectric and mechanical losses are drastically reduced. Examples are Fe^{3+} or Sc^{3+} for $(\text{Zr}, \text{Ti})^{4+}$ or K^{1+} for Pb^{2+} . The basic composition may comprise, in certain quantities, zirconium, titanium, iron and oxygen in a basic molar composition wherein the lead on the one hand and the strontium and/or calcium and/or barium on the other hand, are present in respective percentages of approximately 94 and 6, the zirconium and titanium in respective percentage of approximately 53 and 47 with the relationship between zirconium plus titanium being approximately 97.6 in proportion to iron, 2.4 and to oxygen 298.8. While the above described material is preferred

the invention is not limited thereto. This preferred material is described in U.S. Pat. No. 3,068,177 to Sugden.

The piezoelectric element in the form of a bar or plate 10 is electroded to provide a pair of input and a pair of output electrodes, the electroding being accomplished in the conventional manner. In order to reduce the number of required electrodes, each pair of electrodes consists of input electrode 12 and output electrode 14 with a third electrode serving as a "common" for electrodes 12 and 14. In other words, in the context of this description, electrodes 12 and 16 are considered a pair as well as electrodes 14 and 16. In the preferred embodiment the input and output electrodes 12 and 14 are placed, as shown in the drawing, on one major surface of the plate 10 with a spacing 18 being provided therebetween. The electrodes 12, 14 are thus co-planar and the common electrode 16 placed on the bottom of the plate 10 is continuous and extends parallel to and coextensive with electrodes 12, 14.

The monolithic piezoelectric element 10 is preferably resiliently mounted at the nodal point or points to avoid constraining the element and establishing elastic losses. FIG. 1b illustrates a nodal mounting of the element, by means of an elastic support member 11, such as vulcanized rubber, to effect that the element mechanically resonates at $1/2$ acoustic wave-length along its longitudinal length. Referring now to FIG. 1c, which shows an alternative mode for mounting the element 10, two resilient mounting supports 11 are utilized, each of which is spaced $1/4$ of the axial length of element 10 away from the end of the bar, thereby establishing between supports 11 a distance $1/2$ the axial length of the bar 10, for operation at the first overtone or second harmonic, such that there is one acoustic wavelength along the entire length of the piezoelectric bar 10. The piezoelectric element 10 is monolithic and polarized throughout in a direction perpendicular to the major surfaces.

In an operative circuit where only a single gaseous discharge lamp is to be operated, see FIG. 12, the input and common electrodes 12, 16 respectively, are connected to an oscillator circuit 22 at terminals 17 and 19 through leads 21 and 23 in a manner so that the piezoelectric element controls the frequency of the oscillator circuit, typically close to the resonance of the piezoelectric element. The output and common electrodes 14, 16 are connected through leads 25 and 27 to a gaseous discharge lamp 20, which provides an envelope containing an ionizable gas and a pair of electrodes 28 and 30 within the envelope for establishing an electrical path through the gas. Power of 117 volts at 60 hertz is connected to an oscillator circuit 22 through terminals 24 and 26. Alternatively, terminals 24 and 26 may be connected to a battery or other AC or DC supply.

For purposes of illustrating and describing the efficiency of the above described system it is to be assumed that the input voltage is 170 volts, this voltage being the voltage required to match the characteristics of a typical eight-foot long instant start fluorescent lamp, F96T12, using the piezoelectric transformer described in FIGS. 1a-1c; i.e., length 10 cm., width 4 cm. and thickness 0.25 cm.

FIG. 13 shows the efficiency and secondary voltage V_L as functions of load resistance R_L . FIG. 14 shows the load voltage V_L as a function of load current I_L . The operating point for a F96T12 fluorescent lamp is also

noted. Referring specifically to FIG. 14, there is shown a performance diagram to illustrate conditions when the primary voltage is first connected, at which point $I_L = 0$, and a high starting voltage initiates the arc. The build-up time for the voltage is controlled by the effective mechanical Q , or quality factor of the transformer, the build-up to maximum voltage taking roughly Q cycles at the resonant frequency. Since the mechanical Q of the preferred composition is in the range of 500 to 1,000, the build-up time is in the range of 40 milliseconds for 17 kilohertz operation. Typically, the voltage will build up to about 500 volts when breakdown occurs, and this will take only a fraction of the total build-up time or a few milliseconds. As the load current increases the secondary voltage decreases. The actual stable point depends upon the characteristics of the lamp, the primary voltage, and the characteristics of the piezoelectric element.

The performance characteristics illustrated in FIGS. 13 and 14 are based upon a piezoelectric element of the type shown in and described with respect to FIG. 1. In FIG. 13 the load resistance is shown in ohms along the abscissa. The ordinate shows, on the left hand side of the diagram, the load voltage V_L with the input voltage held constant at 170 volts. The ordinate on the right hand side illustrates the power efficiency in percent. For the F96T12 fluorescent lamp and the piezoelectric element described above the stable point is at $I_L = 0.43$ amperes, $V_L = 174$ volts (75 watts). About 8.3 watts power is dissipated due to internal mechanical losses in the transformer, and about 0.4 watts power is dissipated due to internal dielectric losses. It will therefore be appreciated that the overall efficiency is about 90 percent.

The ballast action occurs in the following manner. Any tendency for the lamp current I_L to rise results in a decrease in lamp voltage V_L , which counteracts the tendency for increasing I_L ; i.e., provides ballast action. Furthermore, an increase (or decrease) in primary voltage will at first tend to increase (or decrease) the lamp current I_L with very little change in lamp voltage V_L . A small change in primary voltage will thus cause a small change in lamp current and therefore in light intensity, and this effect can be utilized for dimming, but the inherent regulation effect will be to keep V_L relatively constant.

While the foregoing description elucidates the invention with respect to structure, operation and output characteristics, it will be appreciated that other configurations and operational settings may be utilized. Modifications are shown and described below with reference to FIGS. 2 to 11 and 15 and 16. Such modifications may include elements with much higher step-up ratios V_L/V_{in} . This ratio is dependent upon the load so that configurations with extremely high ratios (V_L/V_{in}) open circuit, i.e., with $I_L = 0$, are not useful for most gaseous discharge lamps. In general, the load impedance in the operating mode should be roughly equal to the capacitive reactance of the output section at the drive frequency. The piezoelectric device can be used effectively to provide, in addition to starting and ballast action, a means of regulating the power input (and thus light output) of a fluorescent lamp. Since even with reduced primary voltage there is sufficient reserve for starting, it is feasible to use control of primary voltage for dimming.

Turning now specifically to the various modifications, reference is had to FIGS. 2 and 2a which illustrates a piezoelectric device that operates on the same principle as aforescribed and which will not be repeated hereafter. More specifically, there is provided a disc 29 of piezoelectric ceramic material having on its upper major surface a peripherally located circular input electrode 32 and a concentrically arranged output electrode 34 located in a manner to be spaced from the input electrode 32. A common electrode 36 is secured to the opposite major surface which in the drawing is on the bottom of the disc. It will be appreciated, of course, that the position of the input and output electrodes 32, 34 may be reversed depending on required impedance and voltage levels and that the designations used herein are for illustrative purposes only. The disc 29 is polarized in an axial direction and thus perpendicular to the plane of electrodes 32, 34 and 36. This device can be operated at the fundamental radial or planar resonance or at the first overtone. If operation is at the first overtone it is desirable to have the distance from the center of the disc to the middle of the space separating electrodes 32, 34 equal to about 0.4 times the radius of the disc to prevent cancellation effects.

FIG. 3 shows a piezoelectric element 38 which is electroded and polarized in the same manner as described with respect to FIG. 1. Input electrode, output electrode and common electrode are 40, 42 and 44. The distinction from FIG. 1 resides mainly in that the element 38 has a square configuration and can be operated in the fundamental square plate breathing mode whereas, as above noted, FIG. 1 resonates in the fundamental length mode or the first overtone.

FIG. 4 illustrates a piezoelectric element, or transducer 46 which is polarized and electroded in a manner substantially similar to element 29 shown in and described with respect to FIG. 2, with the input electrode being designated herein 48, output electrode 50 and the common electrode 52. It is appreciated that the input and output connections can be interchanged. The element 46 can also be operated at the first overtone.

FIG. 5 illustrates a piezoelectric element 54 which is polarized perpendicular to the major surfaces and resonates in the fundamental square plate breathing mode. The input, output and common electrodes are 56, 58 and 60. For symmetrical impedances the two branches of electrode 56 have widths each approximately one-quarter the side as does the center branch of electrode 58. The outside branches of electrode 58 are each approximately equal to one-eighth of the side. Many other arrangements can also be used.

FIG. 6 shows a longitudinally shaped piezoelectric element 62 in which one half of the element is electroded in an axial direction on the top and bottom surfaces thereof, see 64, with the region 63 therebetween being polarized in a direction perpendicular to the plane of the input electrode 64 and common electrode 66. The longitudinally extending side or edge located remote from the region 63 is electroded to provide an output electrode 68 with the region defined by the area between region 63 and electrode 68, see 70, being polarized in a direction perpendicular to the major plane of the electrode 68. This device is operated in the width mode fundamental or first overtone, i.e., with particle motion parallel to the width or intermediate dimension of the device. If 68, 64 are the output and input elec-

trodes respectively, this provides much higher step-up of primary voltage for high impedance gaseous discharge lamps than the other devices described heretofore.

FIGS. 7 and 7a illustrate a disc-type piezoelectric element 72 having a circular, centrally located input and common electrode 74, 76 formed on the element 72 at opposite sides thereof with the output electrode, see 78, being formed on the circumferential edge or side of the disc 72. The region 80, defined by the volume between electrodes 74 and 76, is polarized in the direction perpendicular to these electrodes while the region 82, defined by the volume located radially between region 80 and the circumferentially formed electrode 78, is polarized in a radial direction. This device can operate at the fundamental radial mode or the first overtone. The electrodes 74, 76 should have a diameter of about 0.4 times the diameter of element 72 for first overtone operation.

The piezoelectric element 84 shown in FIG. 8 has an annular configuration formed with spaced apart electrodes on the outer circular surface of the element to provide an input electrode 86 and an output electrode 88. The electrode formed on the inner surface of the annular element 84 serves as the common electrode 90. The common electrode 90 is axially coextensive to the extreme axial ends of electrodes 86 and 88. The annular element 84 is polarized in a radial direction perpendicular to electrodes 86, 88 to operate at either the fundamental resonance, i.e., where the axial length is one-half acoustic wavelength, or at the first overtone, i.e., where the axial length is one acoustic wavelength.

FIG. 9 also illustrates a piezoelectric element which is annularly shaped but in which the output electrode 94 is located on the axial end face of the annular element whereas the input and common electrodes 96, 98 are located on the inner and outer surfaces of the element. The electrodes 96 and 98 extend approximately one-half of the axial length of the element 92. The element is effective to operate in the axial mode in which the resonant frequency is controlled by the axial dimension. The region defined by the volume between the electrodes 96 and 98 is polarized in a radial direction whereas the remaining portion of the element 92 (in the drawing, the upper half of the annular member) has a polarization directed parallel the central axis of member 92 and thereby is perpendicular to the plane of the output electrode 94. The element is effective to operate either at the fundamental axial mode where the acoustic half wavelength is equal to the axial dimension, or at the first overtone, i.e., where the acoustic wavelength is equal to the axial dimension.

In FIG. 10 there is also shown a piezoelectric element of annular configuration, see 100, and in which the common electrode 102 is formed on the inner periphery of the element. The electrode formed on the outer circumferential surface of the element is split into two approximately equal sections which are spaced relative to each other, see 104, 106, one of which serves as the input electrode and the other as the output electrode. The element 100 is polarized in a radial direction. The element operates in the circumferential or hoop mode. The element is effective to operate at the fundamental mode, i.e., where the half circumference is equal to one-half the acoustic wavelength, or at the first overtone where the half circumference is equal to an acoustic wavelength.

Referring now to FIG. 11 it should be observed that, generally, two electrical systems can be utilized in conjunction with resonating piezoelectric transformer elements for operating gaseous discharge lamps. One such system has already been described with respect to FIG. 12 in which a single piezoelectric element operates a single gaseous discharge lamp and controls a self-oscillating circuit. It is also possible to build and operate a multiple system in which a plurality of gaseous discharge devices are operated by a plurality of piezoelectric transformer elements. Referring more specifically to FIG. 11 there is shown an input line for delivering 117 volts at 60 hertz to terminals 108 and 110 of a frequency changer 112. The frequency changer 112 may be a motor generator set or an electric-type frequency changer utilizing silicon controlled rectifiers. The frequency changer 112 is provided with output terminals 114 and 116 which are connected to the input terminals 118 and electrodes 12 of a plurality of piezoelectric transformers 10a, 10b and 10c. The common electrodes 16 of the piezoelectric transformers are connected by means of terminals 120, 122 and 124 and connecting lines 126, 128 and 130, respectively to the output terminal 116. The output electrode 14 of each element is connected through lines 134, 136, 138 to electrodes of individual gaseous discharge lamps, see 20a, 20b, 20c with the circuit being completed by a line extending from each gaseous discharge lamp 20a, 20b, 20c to output terminal 116, see lines 140, 142, 144, respectively.

The input lines to the frequency changer 112 extend from a standard main which delivers 117 volts 60 hertz. It is also possible to use 230 volts at 60 hertz in a system requiring higher voltage. The frequency changer 112 would have to accommodate the higher input voltage. The output voltage of the frequency changer, the piezoelectric transformer and the gaseous discharge lamp would, in that case, have to be matched and therefore a specific output voltage from the frequency changer must be called for. This is not extremely critical; however, lamp operation should be in a range specified by the manufacturer. The frequency of the output voltage of the frequency changer has to correspond to the resonant frequency of the piezoelectric transformer which is to say that all piezoelectric transformers have to be fairly closely matched to the same resonant frequency and this frequency has to correspond closely to the output frequency of the frequency changer. Typically, for exemplary purposes, the values may be in the range of 150 volts at the output of the frequency changer for large fluorescent lamps and in the order of 100 volts for smaller fluorescent lamps. A typical frequency may be 20 to 30 kilohertz.

With the piezoelectric transformers described above, with the exception of the configuration of FIG. 10, elastic motion occurs primarily only from narrow edges rather than from the major surfaces. Nevertheless, in order to eliminate entirely any audible vibration it is desirable that the resonant frequency of the transformers be in a range above 15 kilohertz. Since no commercial application for piezoelectric transformers are known, at the present time, for frequencies above 200 or 300 kilohertz, it may be stated that the preferred range of the transformers in accordance with this invention should resonate at a frequency between 15 and 300 kilohertz.

While the present invention has been described with respect to piezoelectric elements for starting and operating ballast operation for gaseous discharge devices and in which each of such piezoelectric elements are provided with two pairs of electrodes, (in the sense that the term "pair" is used herein) it is also possible to utilize the invention in conjunction with a monolithic piezoelectric element having a series of secondary electrodes which are connected electrically in series to provide a high secondary voltage. This type of modification is of particular benefit in those applications in which a higher output impedance level is desired.

Referring specifically to FIG. 15, there is shown a piezoelectric element or transformer 146 having input electrodes 148 and 150 with the polarization of the region between the electrodes 148 and 150 being directed perpendicular to the major plane of the electrodes. A second pair of electrodes is located opposite each other, see 152, 154 and a third pair is located at the end opposite to that of electrodes 148, 150, see 156, 158. The region of the piezoelectric element between electrodes 152 and 154 is also poled perpendicular to the plane of the major surface of these electrodes. The electrode 154 serves as a common and the electrode 152 is connected to electrode 158 and the output of the element 146 is taken from electrode 156.

The input section of the piezoelectric element which is defined by the region circumscribed by electrodes 148 and 150 may have approximately one-half the length of the piezoelectric element. The other half of the piezoelectric element constitutes the output section which includes two pairs of electrodes, as above described, 152, 154 and 156, 158. The pairs of electrodes of the output section are connected so that the voltages developed in the output section are added in phase. The electrodes 150 and 154 which are grounded may actually be connected together directly on the surface of the element. A piezoelectric transformer of this type may also be divided into a larger number of output sections connected in series in like fashion. Generally, the spacing between the electrode pairs such as 152, 154 and 156, 158 should be somewhat larger than the thickness of the element. A transformer device of this type can be operated either at the fundamental frequency, i.e., where the length equals one-half acoustic wavelength or, at the first overtone where the length equals one acoustic wavelength.

FIG. 16 illustrates an alternative arrangement. Herein, a piezoelectric element 159 is shown having a pair of input electrodes 160, 162 which define a region which is poled perpendicular to the major plane of the electrodes and the pairs of output electrodes 164, 166 and 168, 170 are connected in series. The polarization of the region defined by the volume between the electrode pair 164, 166 is directed oppositely to that of the region defined by the volume between electrodes 168 and 170. In this embodiment, the electrodes 164 and 168 may be connected together directly on the surface of the element and the electrodes 162 and 166 may be connected together in like fashion. The piezoelectric transformer is operable either at the fundamental resonance where the length is equal to one-half acoustic wavelength or at the first overtone where the length is equal to one acoustic wavelength.

Those skilled in the art will appreciate that the input and output sections shown in FIGS. 15 and 16 can be reversed. In the arrangement shown, i.e., with output electrodes 156 and 170, the output voltage will be higher than the input voltage with near optimum electrical loading. If the opposite were desired and one wanted to obtain a higher output current than input current, the input and output connections shown would be reversed.

The transformer configurations of FIGS. 1-7, 10, 15-16 have the resonance frequency determined by the major dimensions of the piezoelectric element. The intermediate dimension determines the resonance frequencies in transformer configurations of FIGS. 6, 8-9.

While there have been described what are at present considered to be the preferred embodiments of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and it is aimed, therefore, in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. A gaseous discharge lamp lighting system comprising:
 - an envelope containing an ionizable gas, a pair of electrodes within said envelope for establishing an electrical path through said gas;
 - piezoelectric means effective to provide a relatively high starting voltage and a limitation upon the operating current of said lamp, said piezoelectric means consisting of a monolithic piezoelectric plate having at least three physically separate electrodes on the major faces of said plate with two of said at least three electrodes being connected to an AC electrical power source and two of said at least three electrodes connected to said pair of electrodes within said envelope, said plate being polarized parallel to the thickness dimension, and having a lateral dimension selected to provide an extensional mode resonance coinciding substantially with the frequency of said electrical power source.
2. A lighting system according to claim 1, wherein the major strain in said piezoelectric element occurs perpendicular to one of the minor surfaces thereof.
3. A lighting system according to claim 1, wherein said power input source includes a frequency changer, and a plurality of elements and lamps all electrically connected to said frequency changer.
4. A lighting system according to claim 1, wherein said power input source includes an oscillator circuit electrically connected to said element, with said element being effective to control the frequency of the oscillator circuit.
5. A lighting system according to claim 1, wherein said element comprises input and output sections, at least one section having a plurality of electrode pairs connected in series.
6. A lighting system according to claim 1, and resilient mounting means for arranging said element on a support, wherein said mounting means bears upon said element at the nodal point or points.

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