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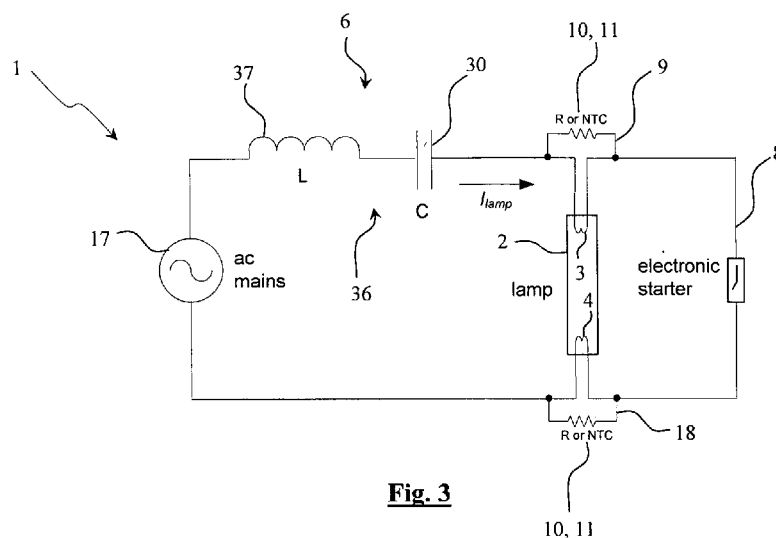
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(54) Title: DISCHARGE LAMP AND METHOD OF MANUFACTURING DISCHARGE LAMP

**Fig. 3**

(57) Abstract: A discharge lamp includes a discharge tube (2) and two filaments (3,4), one at either end of the discharge tube (2) for generating a lamp arc between the filaments (3,4). Each filament (3,4) has a first end (5) connected to a power supply circuit (6) and a second end (7) connected to a starter circuit (8). At least one filament (3,4) is connected to a current control circuit (9). The power supply circuit (6) includes a passive LC ballast having an inductance and a capacitance such that the lamp operates at a predetermined lamp power. The inductance and the capacitance thereby define an inductance-capacitance pair. Method of manufacturing a discharge lamp is provided.

TITLE OF THE INVENTION

A Discharge Lamp and Method of Manufacturing a Discharge Lamp

FIELD OF THE INVENTION

The present invention relates to discharge lamps. The invention is herein described
5 for use with discharge lamps with passive ballasts, but it will be appreciated that the
invention is not limited to this particular use.

BACKGROUND OF THE INVENTION

Discharge lamps typically include a discharge tube having a filament at each end for
generating a lamp arc between the filaments. A problem suffered by these discharge lamps is
10 that an applied current may overheat part of the filaments of the lamp. The high
temperature of the filament will vaporize the filament materials and cause the blackening of
the two ends of the lamp quickly, leading to a reduction of the lifetime of the lamp.

The problem arises because an electronic starter is usually used to ignite these lamps,
as shown in Fig. 1. After lamp ignition, the electronic starter is opened, resulting in an open
15 circuit. Since only one end of each filament is connected to the external power supply circuit,
the flow of electrons (current) from the filament to the lamp arc is uneven as illustrated in
Fig. 2. The ends of the filaments connected to the electronic starter play a much smaller part
in emitting electrons into the discharge tube, while the ends of the filaments connected to
the external power supply circuit play a more significant part in emitting electrons. This
20 uneven current emission density along the filament into the lamp arc will cause excessive hot
spots in the filament as explained in the paper titled "Thermal Model of Fluorescent Lamp

- 2 -

Electrode” by T.E. Soules, J.H. Ingold, A.K. Bhattacharya and R.H. Springer, Journal of Illuminating Engineering Society, Summer 1989, pp.81-92.

It is an object of the present invention to overcome or ameliorate at least one of the disadvantages of the prior art, or to provide a useful alternative.

5 SUMMARY OF THE INVENTION

In a first aspect, the present invention provides a discharge lamp including: a discharge tube; two filaments, one at either end of the discharge tube for generating a lamp arc between the filaments, each filament having a first end connected to a power supply circuit and a second end connected to a starter circuit; and at least one current control circuit
10 connected to one of the filaments.

In one embodiment, the current control circuit includes a resistor connected in parallel across said one filament. Preferably, said one filament has a cold filament resistance and a heated filament resistance, and the resistor has a resistor resistance between the cold and heated filament resistances.

15 In another embodiment, the current control circuit includes a negative-temperature-coefficient thermistor connected in parallel across said one filament. Preferably, said one filament has a cold filament resistance and a heated filament resistance, and the negative-temperature-coefficient thermistor has a cold thermistor resistance that is higher than the cold filament resistance, and a heated thermistor resistance that is lower than the heated
20 filament resistance.

- 3 -

In a further embodiment, the current control circuit includes a first diode connected in series with said one filament, and a second diode connected in parallel across the first diode and said one filament such that current is allowed to flow into both the first and second ends.

- 5 Preferably, the discharge lamp includes a second current control circuit connected to the other of the filaments.

- In yet another embodiment, the current control circuit includes a transformer having a primary winding connected to a power supply and a secondary winding connected in parallel across said one filament to provide a heating current to the second end of said one
10 filament. Preferably, the transformer has a second secondary winding connected in parallel across the other of the filaments to provide a heating current to the second end of said other filament.

- Preferably, the discharge lamp includes a relay connected to the starter circuit and at least one of the current control circuits such that: when the starter circuit is open, the relay is
15 closed to connect the current control circuit to said one filament; and when the starter circuit is closed, the relay is open to disconnect the current control circuit from said one filament.

Preferably, the discharge lamp includes a preheat circuit to preheat the discharge lamp during a preheat period before ignition of the discharge lamp.

- Preferably, the preheat circuit disconnects each current control circuit during the
20 preheat period thereby allowing more current to preheat the filaments, and connects each current control circuit after the preheat period.

- 4 -

Preferably, the preheat circuit includes a respective preheat switch connected to each current control circuit, the preheat circuit disconnecting each current control circuit during the preheat period by maintaining each respective preheat switch open during the preheat period, and connecting each current control circuit after the preheat period by maintaining each respective preheat switch closed after the preheat period. Preferably, each respective preheat switch is normally-closed. Preferably, each respective preheat switch forms part of a preheat relay circuit.

Preferably, the preheat circuit includes a preheat capacitor to provide power to open each respective preheat switch. Also preferably, the preheat circuit includes a preheat diode rectifier for rectifying a preheat current that charges the preheat capacitor. The power supply circuit preferably provides the preheat current via the starter circuit. Preferably, the starter circuit determines the preheat period.

Preferably, after the preheat period a large voltage develops across the filaments to generate the lamp arc.

Preferably, the preheat circuit includes a discharge resistor connected in parallel across the preheat capacitor for discharging the preheat capacitor after the preheat period. Preferably, the preheat circuit includes a preheat diode connected in parallel across the preheat capacitor such that the voltage across the preheat capacitor is DC with suitable polarity.

Preferably, the discharge lamp optionally includes a low-temperature circuit to warm up the discharge lamp in low temperature operating conditions during a warm-up period before ignition of the discharge lamp.

- 5 -

Preferably, the power supply circuit includes a capacitor, and wherein the low-temperature circuit includes a warm-up capacitor, the low-temperature circuit connecting the warm-up capacitor in parallel across the capacitor during the warm-up period thereby allowing more current to warm up the filaments, and disconnecting the warm-up capacitor
5 after the warm-up period.

Preferably, the low-temperature circuit includes a warm-up switch, the low-temperature circuit connecting the warm-up capacitor in parallel across the capacitor during the warm-up period by maintaining the warm-up switch closed during the warm-up period, and disconnecting the warm-up capacitor after the warm-up period by maintaining the
10 warm-up switch open after the warm-up period. Preferably, the warm-up switch is normally-open. Preferably, the warm-up switch forms part of a warm-up relay circuit.

Preferably, the power supply circuit provides a warm-up current via the starter circuit to close the warm-up switch. Preferably, the low-temperature circuit includes a warm-up diode rectifier for rectifying the warm-up current. Preferably, the low-temperature circuit
15 includes a warm-up controller.

Preferably, the power supply circuit includes a passive LC ballast.

In one embodiment, the discharge lamp is a T5-14W lamp and the passive LC ballast includes an inductor and a capacitor, and the current control circuit includes a bypass switch connected across the capacitor, the bypass switch adapted to be open during ignition of the
20 discharge lamp so that both the inductor and the capacitor are connected, and closed after ignition of the discharge lamp so that only the inductor is connected.

- 6 -

In a second aspect, the present invention provides a method of manufacturing a discharge lamp, the discharge lamp including: a discharge tube; and two filaments, one at either end of the discharge tube for generating a lamp arc between the filaments, each filament having a first end connected to a power supply circuit and a second end connected to a starter circuit; the method including the step of connecting at least one current control circuit to one of the filaments.

In one embodiment, the step of connecting the current control circuit includes connecting a resistor in parallel across said one filament.

In another embodiment, the step of connecting the current control circuit includes connecting a negative-temperature-coefficient thermistor in parallel across said one filament.

In a further embodiment, the step of connecting the current control circuit includes connecting a first diode in series with said one filament, and connecting a second diode in parallel across the first diode and said one filament such that current is allowed to flow into both the first and second ends.

Preferably, the method includes the step of connecting a second current control circuit to the other of the filaments.

In yet another embodiment, the step of connecting the current control circuit includes connecting a primary winding of a transformer to a power supply and connecting a secondary winding of the transformer in parallel across said one filament to provide a heating current to the second end of said one filament. Preferably, the step of connecting the current control circuit includes connecting a second secondary winding of the

- 7 -

transformer in parallel across the other of the filaments to provide a heating current to the second end of said other filament.

Preferably, the method includes the step of connecting a relay to the starter circuit and at least one of the current control circuits such that: when the starter circuit is open, the
5 relay is closed to connect the current control circuit to said one filament; and when the starter circuit is closed, the relay is open to disconnect the current control circuit from said one filament.

Preferably, the method includes the step of preheating the discharge lamp during a preheat period before ignition of the discharge lamp.

10 Preferably, the method includes the steps of disconnecting each current control circuit during the preheat period thereby allowing more current to preheat the filaments, and connecting each current control circuit after the preheat period.

Preferably, the method includes the steps of providing a respective preheat switch connected to each current control circuit, maintaining each respective preheat switch open
15 during the preheat period to disconnect each current control circuit during the preheat period, and maintaining each respective preheat switch closed after the preheat period to connect each current control circuit after the preheat period. Preferably, each respective preheat switch is normally-closed. Preferably, each respective preheat switch is provided as part of a preheat relay circuit.

20 Preferably, the method includes the step of providing power to open each respective preheat switch, preferably by using a preheat capacitor. Preferably, the method includes the step of rectifying a preheat current that charges the preheat capacitor, preferably by using a

- 8 -

preheat diode rectifier. Preferably, the method includes the step of providing the preheat current via the starter circuit. Preferably, the method includes the step of providing the preheat current with the power supply circuit. Preferably, the method includes the step of determining the preheat period with the starter circuit.

- 5 Preferably, the method includes the step of developing, after the preheat period, a large voltage across the filaments to generate the lamp arc.

- Preferably, the method includes the step of discharging the preheat capacitor after the preheat period, preferably by using a discharge resistor connected in parallel across the preheat capacitor. Preferably, the method includes the step of maintaining the voltage across
10 the preheat capacitor as DC with suitable polarity, preferably by using a preheat diode connected in parallel across the preheat capacitor.

 Preferably, the method includes the step of connecting a preheat circuit to preheat the discharge lamp during a preheat period before ignition of the discharge lamp. In one embodiment, the preheat circuit is in accordance with the preheat circuit described above.

- 15 Preferably, the method optionally includes the step of warming up the discharge lamp in low temperature operating conditions during a warm-up period before ignition of the discharge lamp.

- Preferably, the power supply circuit includes a capacitor, and the method includes the steps of connecting a warm-up capacitor in parallel across the capacitor during the
20 warm-up period thereby allowing more current to warm up the filaments, and disconnecting the warm-up capacitor after the warm-up period.

- 9 -

Preferably, the method includes the steps of providing a warm-up switch, maintaining the warm-up switch closed during the warm-up period to connect the warm-up capacitor in parallel across the capacitor during the warm-up period, and maintaining the warm-up switch open after the warm-up period to disconnect the warm-up capacitor after
5 the warm-up period. Preferably, the warm-up switch is normally-open. Preferably, the warm-up switch is provided as part of a warm-up relay circuit.

Preferably, the method includes the step of providing a warm-up current via the starter circuit to close the warm-up switch. Preferably, the method includes the step of providing the warm-up current with the power supply circuit. Preferably, the method
10 includes the step of rectifying the warm-up current, preferably by using a warm-up diode rectifier. Preferably, the method includes the step of providing a warm-up controller.

Preferably, the method optionally includes the step of connecting a low-temperature circuit to warm up the discharge lamp in low temperature operating conditions during a warm-up period before ignition of the discharge lamp. In one embodiment, the low-
15 temperature circuit is in accordance with the low-temperature circuit described above.

In one embodiment, the discharge lamp is a T5-14W lamp and the power supply circuit includes a passive LC ballast having an inductor and a capacitor, and the method includes the steps of connecting both the inductor and the capacitor during ignition of the discharge lamp, and connecting only the inductor after ignition of the discharge lamp.

20 Preferably, the method includes the steps of connecting a bypass switch across the capacitor, opening the bypass switch during ignition of the discharge lamp to connect both

- 10 -

the inductor and the capacitor, and closing the bypass switch after ignition of the discharge lamp to connect only the inductor.

BRIEF DESCRIPTION OF THE FIGURES

Preferred embodiments in accordance with the best mode of the present invention will now be described, by way of example only, with reference to the accompanying figures, in which:

Figure 1 is a circuit diagram of a typical circuit for an LC (inductive-capacitive) resonant ballast;

Figure 2 is a wiring diagram of a discharge lamp of the prior art, together with a graph of the current density across each filament;

Figure 3 is a circuit diagram of a discharge lamp in accordance with an embodiment of the present invention;

Figure 4 are graphs of the current density across each filament of the discharge lamp of Figure 3;

Figure 5 is a circuit diagram of a discharge lamp in accordance with another embodiment of the present invention;

Figure 6 is a circuit diagram of a discharge lamp in accordance with a further embodiment of the present invention;

Figure 7 is a circuit diagram of a discharge lamp in accordance with yet another embodiment of the present invention, which includes a relay shown in a closed state;

- 11 -

Figure 8 is a circuit diagram of the discharge lamp of Figure 7 with the relay shown in an open state;

Figure 9 is a graph showing various electrical parameters of the discharge lamp of Figure 7 when in operation;

5 Figure 10 is a circuit diagram of a discharge lamp in accordance with another embodiment of the present invention;

Figure 11 is a circuit diagram of a discharge lamp in accordance with a further embodiment of the present invention;

Figure 12 is a circuit diagram of a discharge lamp in accordance with yet another
10 embodiment of the present invention;

Figure 13 is a circuit diagram of a discharge lamp in accordance with an embodiment of the present invention having a preheat circuit and a warm-up circuit;

Figure 14 is a circuit diagram of the discharge lamp of Figure 13 showing the conducting paths before ignition;

15 Figure 15 is a circuit diagram of the discharge lamp of Figure 13 showing the conducting paths after ignition; and

Figure 16 is a circuit diagram of a discharge lamp in accordance with a further embodiment of the present invention.

- 12 -

DETAILED DESCRIPTION OF THE BEST MODE OF THE INVENTION

Referring to the figures, the present invention provides a discharge lamp 1 including a discharge tube 2, and two filaments 3 and 4, one at either end of the discharge tube for generating a lamp arc between the filaments. Each filament 3 and 4 has a first end 5 connected to a power supply circuit 6 and a second end 7 connected to a starter circuit 8. Generally, a current control circuit 9 is connected to one of the filaments 3 or 4.

In the embodiment shown in Figs. 3 and 4, the current control circuit 9 includes either a resistor 10 or a negative-temperature-coefficient (NTC) thermistor 11 connected in parallel across the filament 3. As an alternative, an equivalent component to the resistor or NTC thermistor can be used.

In the case of the resistor 10, the filament 3 has a cold filament resistance and a heated filament resistance, and the resistor 10 has a resistor resistance between the cold and heated filament resistances. Before ignition, the filament 3 is cold and its resistance is less than that when the filament is heated. Since the resistance of the resistor 10 is higher than the cold filament resistance, a pre-ignition current will tend to flow into the filament 3 when the starter circuit 8 allows the pre-ignition current to flow. After the lamp 1 is ignited and the filament 3 is heated, the heated filament resistance will be higher than the resistance of the resistor 10. This allows the resistor 10 to channel some current to flow into the second end 7 of the filament 3 that is connected to the starter circuit 8. Consequently, current can flow into both ends 5 and 7 of the filament 3, resulting in a more even current density emission and heat distribution along the filament 3. This method will reduce the chance of forming excessive hot spots in the filaments by (i) reducing the peak current density in one

- 13 -

end of each filament and (2) offering a more even heat distribution in the filament as shown in Fig. 4.

In the case of the NTC thermistor 11, the filament 3 has a cold filament resistance and a heated filament resistance, and the NTC thermistor 11 has a cold thermistor resistance that is higher than the cold filament resistance, and a heated thermistor resistance that is lower than the heated filament resistance. An NTC thermistor is a device that has high resistance when it is cold and low resistance when it is hot. Before lamp ignition, both the filament 3 and NTC thermistor 11 are cold. The high resistance of the NTC thermistor 11 ensures that the filament pre-ignition current will primarily flow into the filament 3 for warm-up or preheating purposes. After lamp ignition, the NTC thermistor 11 is also warmed up. The resistance of the NTC thermistor 11 will then drop. The resulting resistance of the NTC thermistor 11 is then lower than that of the heated filament resistance. This allows the NTC thermistor 11 to channel some current to the second end 7 of the filament 3 that is connected to the starter circuit 8 as described previously.

In the embodiment shown in Fig. 5, the current control circuit 9 includes a first diode 12 connected in series with the filament 3, and a second diode 13 connected in parallel across the first diode and the filament such that current is allowed to flow into both the first and second ends 5 and 7. It will be appreciated that the first and second diodes 12 and 13 can have a number of configurations. In the embodiment shown, the first diode 12 is connected in series between the power supply circuit 6 and the filament 3 and is forward-biased towards the filament 3. The second diode 13 is biased in the opposite direction to the first diode 12.

- 14 -

In the embodiment shown in Fig. 6, the current control circuit 9 includes a secondary winding 14 connected in parallel across the filament 3, the secondary winding forming part of a transformer 15 having a primary winding 16 connected to a power supply 17.

5 Typically, a second current control circuit 18 is connected to the other of the filaments 3 and 4. In the embodiments shown in Figs. 4, 5 and 6, the second current control circuit 18 is connected to the filament 4. In these particular embodiments, the second current control circuit 18 is identical to the first current control circuit 9. It will be appreciated, however, that the current control circuits 9 and 18 can be different. Although
10 in some embodiments, they must be arranged in a particular manner. For example, in the embodiment shown in Figure 5, the first and second current control circuits 9 and 18 must be the same. In the embodiment shown in Fig. 5, the second current control circuit 18 is connected to the filament 4, such that the transformer 15 includes two secondary windings 14 and the primary winding 16 connected to the power supply 17.

15 The embodiment depicted in Figs. 7 and 8 show a variation of the embodiment depicted in Fig. 3 and described above. This variation is useful because the resistors 10 or NTC thermistors 11 may divert some of the pre-ignition current away from the filaments 3 and 4. This may affect the pre-ignition process of warming up the filaments 3 and 4 and result in possible blackening of the ends of the lamp.

20 In the embodiment shown in Figs. 7 and 8, the discharge lamp 1 includes a relay circuit 19 connected to the current control circuit 9 and the starter circuit 8 such that: when the starter circuit is open, as shown in Fig. 7, the relay circuit 19 is closed to connect the current control circuit 9 to the filament 3; and when the starter circuit is closed, as shown in

- 15 -

Fig. 8, the relay circuit 19 is open to disconnect the current control circuit 9 from the filament 3. In the particular embodiment shown, the relay circuit 19 is also connected to the second current control circuit 18 whilst being connected to the starter circuit 8 such that: when the starter circuit is open, as shown in Fig. 7, the relay circuit 19 is closed to connect
5 the second current control circuit 18 to the filament 4; and when the starter circuit is closed, as shown in Fig. 8, the relay circuit 19 is open to disconnect the second current control circuit 18 from the filament 4. It will be appreciated, however, that in other embodiments the relay circuit 19 only connects to one of the current control circuits 9 and 18.

More particularly, Fig. 7 shows the circuit diagram and condition of a practical
10 implementation of the embodiment when the lamp 1 is already operating (conducting) after ignition. Under normal lamp operation after lamp ignition, the starter circuit 8 is opened. In this particular embodiment, the relay circuit 19 includes two normally-closed relay switches 20. Without current from the starter circuit, the normally-closed relay switches 20 are closed, thereby connecting the resistors 10 across their respective lamp filaments 3 and 4 for
15 avoiding hot spot formation in the filaments.

Fig. 8 shows the circuit diagram and condition of the embodiment during the pre-ignition process (before the lamp 1 is turned on). Under this condition, the starter circuit 8 is turned on to allow the pre-ignition current to flow into the filaments 3 and 4. The starter current will switch the normally-closed relay switches 20 to open so that the resistors 10
20 across the filaments 3 and 4 will be disconnected from the filaments. In this way, all the pre-ignition current will flow into the filaments 3 and 4 through the starter circuit 8.

Fig. 9 shows the practical results of such an embodiment. A pre-ignition time of about 2 seconds can be observed in this practical example. During the pre-ignition period,

- 16 -

the resistor current is zero and all the pre-ignition current flows into the filaments 3 and 4 through the starter circuit 8. At the end of the pre-ignition period, a large ignition voltage (a large negative voltage spike of about 1.4kV in the captured lamp voltage waveform shown) is generated and then the lamp 1 is turned on. After the turn-on of the lamp, resistor current
5 becomes available, confirming that the resistors 10 are only connected across the filaments 3 and 4 after the pre-ignition period and the starter circuit 8 is turned off.

Figs. 10 to 12 show embodiments similar to the embodiments described above except that they have been applied to power supplies having transformers such as those in 110V ~ 120V systems.

10 As shown in Figs. 13 to 15, the discharge lamp 1 can include a preheat circuit 21 to preheat the discharge lamp during a preheat period before ignition of the discharge lamp. Applied to the present embodiments, the preheat circuit 21 disconnects each current control circuit 9 and 18 during the preheat period thereby allowing more current to preheat the filaments 3 and 4, and connects each current control circuit 9 and 18 after the preheat
15 period.

More particularly, the preheat circuit 21 includes a respective preheat switch 22 and 23 connected to each current control circuit 9 and 18. The preheat circuit 21 disconnects each current control circuit 9 and 18 during the preheat period by maintaining each respective preheat switch 22 and 23 open during the preheat period, and connects each
20 current control circuit 9 and 18 after the preheat period by maintaining each respective preheat switch 22 and 23 closed after the preheat period.

- 17 -

Each respective preheat switch 22 and 23 is normally-closed. The preheat circuit 21 includes a preheat capacitor 24 to provide power to open each respective preheat switch. The preheat circuit 21 also includes a preheat diode rectifier 25 for rectifying a preheat current that charges the preheat capacitor 24. The power supply circuit 6 provides the
5 preheat current via the starter circuit 8.

The starter circuit 8 determines the preheat period. After turning on the power supply 17, a current is driven through the power supply circuit 6 into the filaments 3 and 4 via the starter circuit 8 and the preheat switches 22 and 23. The preheat diode rectifier 25 rectifies a preheat current which charges up the preheat capacitor 24. The voltage across the
10 preheat capacitor 24 provides the power to open the preheat switches 22 and 23. This results in the current control circuits 9 and 18 being disconnected during the preheat period. After the preheat period, the starter circuit 8 will turn off to interrupt the preheat current. At this time, a large voltage develops across the filaments 3 and 4 to generate the lamp arc.

The preheat circuit 21 includes a discharge resistor 26 connected in parallel across
15 the preheat capacitor 24 for discharging the preheat capacitor after the preheat period. The preheat circuit 21 also includes a preheat diode 27 connected in parallel across the preheat capacitor 24 such that the voltage across the preheat capacitor is DC with suitable polarity. Further, each respective preheat switch 22 and 23 forms part of a preheat relay circuit 28.

The discharge lamp 1 can optionally include a low-temperature circuit 29 for
20 operation at low temperatures, including extreme low temperature, such as -15°C, which is the usual minimum operating temperature of T5 fluorescent lamps. At these low temperatures, starting the lamp requires a higher than normal filament and lamp current in order to warm up the filaments and the plasma inside the fluorescent lamp.

- 18 -

The low-temperature circuit 29 warms up the discharge lamp 1 in these low temperature operating conditions during a warm-up period before ignition of the discharge lamp 1.

In embodiments where the power supply circuit 6 includes a capacitor 30, the low-temperature circuit 29 includes a warm-up capacitor 31. The low-temperature circuit 29 connects the warm-up capacitor 31 in parallel across the capacitor 30 during the warm-up period thereby allowing more current to warm up the filaments, and disconnects the warm-up capacitor 31 after the warm-up period.

More particularly, the low-temperature circuit 29 includes a warm-up switch 32, and the low-temperature circuit 29 connects the warm-up capacitor 31 in parallel across the capacitor 30 during the warm-up period by maintaining the warm-up switch 32 closed during the warm-up period, and disconnects the warm-up capacitor 31 after the warm-up period by maintaining the warm-up switch 32 open after the warm-up period.

The warm-up switch 32 is normally-open. The power supply circuit 6 provides a warm-up current via the starter circuit 8 to close the warm-up switch 32. The low-temperature circuit 29 includes a warm-up diode rectifier 33 for rectifying the warm-up current. The low-temperature circuit 29 includes a warm-up controller 34. Furthermore, the warm-up switch 32 forms part of a warm-up relay circuit 35.

The specific embodiment of the discharge lamp 1 shown in Figs. 13 to 15 includes both a preheat circuit 21 and a warm-up circuit 29. The power supply circuit 6 includes a passive LC ballast 36, which includes the capacitor 30 and an inductor 37.

- 19 -

Referring to this specific embodiment, one end of the resistor 10 (also known as the bypass resistor) is connected to a preheat switch (preheat switch 22 for one resistor 10 and preheat switch 23 for the other resistor 10). The preheat switches 22 and 23 (also labeled in the figures as S2 and S1 respectively) are open initially when the power of the lighting system is turned on. In this embodiment, preheat switches S1 and S2 form part of the preheat relay circuit 28. The preheat relay circuit 28 is of a normally-closed type. This means that the preheat switches S1 and S2 are closed if the preheat relay circuit 28 is not activated. However, it should be noted that electronic switches designed with the same functions of this preheat relay circuit 28 can also be used if desired.

After turn-on, the mains voltage from the power supply 17 drives a current through the LC ballast 36 into the filaments 3 and 4 via the starter circuit 8 (which can be in the form of an electronic starter) and the preheat relay circuit 28 of the preheat circuit 21. The preheat diode rectifier 25 within the preheat circuit 21 rectifies the preheat current, which charges up the preheat capacitor 24 of the preheat relay circuit 28 within the preheat circuit 21. The voltage across the preheat capacitor 24 provides the power to activate the preheat relay circuit 28 which then open (turn off) the switches S1 and S2. This means that the bypass resistors 10 are disconnected during the filament preheat period.

The preheat time is determined by the design of the starter circuit 8. Many existing commercial electronic starters for fluorescent lamps can be used for this purpose. After the preheat period, the starter circuit 8 will turn off to interrupt the preheat current. A large voltage (due to the large di/dt in the inductor 37) will be developed across the two filaments 3 and 4 of the lamp 1 to provide a high ignition voltage for striking the lamp arc. The starter circuit 8 may not cause the arc to strike in one time. In general, it may take the starter circuit

- 20 -

8 only a few times to establish the lamp arc current. Once the starter circuit 8 completes its task and the lamp is turned on, the starter circuit 8 stops conducting. The preheat capacitor 24 of the preheat relay circuit 28 discharges via parallel discharge resistor 26. The preheat diode 27, which is across the parallel discharge resistor 26, is used to ensure that the voltage of the preheat capacitor 24 is a DC one with the right polarity. When the preheat capacitor 24 of the preheat relay circuit 28 is discharged, the preheat relay circuit is deactivated and therefore the preheat switches S1 and S2 revert to the normally-closed state. This means that the two bypass resistors 10 are connected via S1 and S2 respectively across their respective filaments 3 and 4 in order to avoid hot-spot formation in the filaments.

10 It should also be noted that after the lamp is turned on, both the starter circuit 8 and the preheat circuit 21 do not consume energy. Since they are used only during the filament preheat period in pre-ignition (less than a few seconds in total), they are expected to enjoy a long lifetime.

The low-temperature circuit 29 includes the warm-up diode rectifier 33, the controller 34 and the warm-up relay circuit 35 with the warm-up switch 32 (also labeled in the figures as S3). Unlike S1 and S2, S3 of the warm-up relay circuit 35 is a normally-open switch. During the warm-up period, the current goes through the low-temperature circuit 29 via the conducting starter circuit 8, as shown in Fig. 14. The warm-up relay 35 in the low-temperature circuit 29 is powered and activated so that S3 is closed to insert the warm-up capacitor 31 (also labeled in the figures as C1) across the capacitor 30 (also labeled in the figures as C) of the LC ballast 36. With an extra parallel capacitor in the form of C1, the overall capacitance of the LC ballast 36 is increased. The impedance of the equivalent capacitance is lower than that of C. Consequently, more current flows into the filaments 3

- 21 -

and 4 to warm up the lamp (to compensate, for example, for the heat loss in very low ambient temperatures). Once the lamp 1 is properly ignited by the starter circuit 8, the starter circuit 8 stops conducting. The warm-up relay 35 of the low-temperature circuit 29 is deactivated and S3 reverts to its normally-open state. The warm-up capacitor C1 is now
5 disconnected from C. The conducting paths under steady-state lamp operation are shown in Fig. 15.

The present invention also provides a method of manufacturing a discharge lamp, the discharge lamp including: a discharge tube; and two filaments, one at either end of the discharge tube for generating a lamp arc between the filaments, each filament having a first
10 end connected to a power supply circuit and a second end connected to a starter circuit. The method includes the step of connecting at least one current control circuit to one of the filaments. In a preferred embodiment, the current control circuit is the current control circuit 9 described above.

The method can also include the step of preheating the discharge lamp during a
15 preheat period before ignition of the discharge lamp. This can be done by connecting a preheat circuit such as the preheat circuit 21 described above.

The method can also include the step of warming up the discharge lamp in low temperature operating conditions during a warm-up period before ignition of the discharge lamp. This can be done by connecting a low-temperature circuit such as the low-
20 temperature circuit 29 described above.

Other steps in the method will be apparent to those skilled in the art from the description contained herein.

- 22 -

The recent introduction of T5 fluorescent lamps offers probably the most cost effective lighting solution in terms of lumen per watt per dollar for lighting industry. While electronic ballasts were originally promoted as the only type of ballasts for driving T5 lamps, it has been practically proven that an ultra-low-loss passive ballast (as shown in Fig.1), comprising an inductor and a series connected capacitor to form a LC ballast, can in fact outperform electronic ballasts in terms of: (i) energy-efficiency; (ii) lifetime; and (iii) recyclability. See the paper titled "A "Class-A2" ultra-low-loss magnetic ballast for T5 fluorescent lamps" by S.Y.R. Hui, D.Y. Lin, W.M. Ng, and W. Yan, IEEE Applied Power Electronics Conference and Exposition (APEC), 2010 Page(s): 1346 – 1351.

The use of LC ballasts for T5 lamps with a specific range of LC values for optimum performance has been proposed in a previous PCT patent application PCT/IB2009/007289 titled "A Passive LC Ballasts and Method of Manufacturing a Passive LC Ballast" in the name of inventors S.Y.R. Hui, D.Y. Lin and W.M. Ng.

A passive LC ballast according to this previous PCT application has an inductance and a capacitance in accordance with a non-linear model such that a lamp operates at a predetermined lamp power, with the inductance and the capacitance thereby defining an inductance-capacitance pair. The non-linear model defines a range of inductance-capacitance pairs that, when used in an LC ballast, produce an ultra-low-loss (ULL) ballast. The non-linear model is based on equations having unknown coefficients, and the unknown coefficients are in accordance with an evolutionary algorithm, preferably, a genetic algorithm.

One specific embodiment of the linear model is defined by the following equations:

$$\frac{dT_e}{dt} = a_1 (i^2 R - P_{con} - P_{rad});$$

- 23 -

$$P_{rad} = a_2 \exp(-ea_3/kT_e);$$

$$P_{con} = a_4 (T_e - T_0);$$

$$R = a_5 T_e^{-3/4} \exp(ea_6/2kT_e);$$

$$V(t) = a_7 L \frac{di}{dt} + i(R + r) + V_c + v_{ele}; \text{ and}$$

$$5 \quad \frac{dV_c}{dt} = \frac{i}{C};$$

wherein:

T_e is the electron temperature;

i is the lamp current;

R is the lamp resistance;

10 P_{con} is the thermal conduction loss in the lamp;

P_{rad} is the radiation loss in the lamp;

T_0 is the tube temperature;

k is the Boltzmann constant;

e is the charge on an electron;

15 $V(t)$ is the power supply voltage;

L is the ballast inductance;

C is the ballast capacitance;

r is the ballast resistance;

V_{ele} is the electrode voltage drop in the lamp;

20 V_c is the voltage across the capacitor in the LC ballast; and

a_1 to a_7 are unknown coefficients.

- 24 -

The advantages of the ultra-low-loss ballast can be seen from the comparison of traditional T8 36W lamps and T5 28W lamps shown in Table 1 below. It should be noted that T5 lamps are “high-voltage” and “low-current” lamps. The low current feature indicates that the winding conduction loss (i^2R) can be reduced by 84% and the magnetic core loss (which is proportional to current) can be reduced by almost 60%, assuming that the same magnetic ballast is used in both cases.

Lamp Type	T8 36W	T5 28W	Loss reduction
Rated voltage (Vrms)	103	167	
Rated current (Arms)	0.44	0.175	
Conduction loss (i^2R)	100%	16%	84%
Core loss ($\propto I$ or ϕ)	100%	40%	60%

Table 1. Initial assessment of loss components

However, these T5 lamps driven by ultra-low-loss passive ballasts are prone to the problem of local hot spot formation as described above.

In further detail, Fig. 1 shows a discharge lamp that is driven by a passive LC ballast. At the rated lamp power, lamp current is generally slightly larger than the current driven by electronic ballast. More particularly, the lamp power is:

$$P_{lamp} = (V_{lamp-1})(I_{lamp-1})\cos(\phi)$$

where V_{lamp-1} is the rms value of the lamp voltage, I_{lamp-1} is the rms value of the lamp current and ϕ is the phase shift between the lamp voltage and current.

- 25 -

For high-frequency operation, the lamp arc is resistive and so the voltage and current waveforms are in phase, resulting in $\phi = 0$ and $\cos\phi = 1$. However, at mains frequency, the lamp arc will exhibit some inductive effect, although it is still primarily resistive. This means that $\phi \neq 0$ and $\cos\phi < 1$. So for the same lamp power, a slightly higher lamp current I_{lamp} is
5 required.

A larger lamp current may overheat part of the filaments of the lamp. The high temperature of the filament will vaporize the filament materials and cause the blackening of the two ends of the lamp quickly, leading to a reduction of the lifetime of the lamp.

Referring to the circuit depicted in Fig. 1, a starter circuit 8 is used to ignite the lamp.
10 In some embodiments, the starter circuit 8 is an electronic starter. After lamp ignition, this starter circuit 8 is opened, resulting in an open circuit. Since only the first end 5 of each filament 3 and 4 is connected to the power supply circuit 6, the flow of electrons (current) from each filament to the lamp arc is uneven as illustrated in Fig. 2. The second ends 7 of the filaments 3 and 4 connected to the electronic starter 8 play a much smaller part in
15 emitting electrons into the lamp tube 2, while the ends 5 of the filaments 3 and 4 connected to the power supply circuit 6 play a more significant part in emitting electrons. This uneven current emission density along the filaments 3 and 4 into the lamp arc will cause excessive hot spots in the filaments.

The present invention advantageously addresses this problem to vastly improve the
20 lifespan of discharge lamps, including the high performance T5 lamps described above.

In the case of T5-14W lamps with a passive LC ballast having an inductor and a capacitor, there is a further improvement that can be applied, as shown in Fig. 16. T5-14W

- 26 -

lamps do not have a high lamp voltage and therefore do not need the capacitor to compensate for the voltage drop of the inductor. Thus, referring to Fig. 16 which shows an embodiment where the discharge lamp is a T5-14W lamp with a passive LC ballast having an inductor L and a capacitor C, a bypass switch Sb can be connected across the capacitor C, 5 wherein the bypass switch Sb is adapted to be open during ignition of the discharge lamp 1 so that the inductor L and the capacitor C are connected, and closed after ignition of the discharge lamp 1 so that only the inductor L is connected.

Although the invention has been described with reference to specific examples, it will be appreciated by those skilled in the art that the invention can be embodied in many 10 other forms. It will also be appreciated by those skilled in the art that the features of the various examples described can be combined in other combinations.

- 27 -

CLAIMS

1. A discharge lamp including:
 - a discharge tube;
 - two filaments, one at either end of the discharge tube for generating a lamp arc
 - 5 between the filaments, each filament having a first end connected to a power supply circuit and a second end connected to a starter circuit; and
 - at least one current control circuit connected to one of the filaments.
2. A discharge lamp according to claim 1 wherein the current control circuit includes a resistor connected in parallel across said one filament.
- 10 3. A discharge lamp according to claim 2 wherein said one filament has a cold filament resistance and a heated filament resistance, and wherein the resistor has a resistor resistance between the cold and heated filament resistances.
4. A discharge lamp according to claim 1 wherein the current control circuit includes a negative-temperature-coefficient thermistor connected in parallel across said one filament.
- 15 5. A discharge lamp according to claim 4 wherein said one filament has a cold filament resistance and a heated filament resistance, and wherein the negative-temperature-coefficient thermistor has a cold thermistor resistance that is higher than the cold filament resistance, and a heated thermistor resistance that is lower than the heated filament resistance.
6. A discharge lamp according to claim 1 wherein the current control circuit includes a
- 20 first diode connected in series with said one filament, and a second diode connected in

- 28 -

parallel across the first diode and said one filament such that current is allowed to flow into both the first and second ends.

7. A discharge lamp according to claim 1 wherein the current control circuit includes a secondary winding connected in parallel across said one filament, the secondary winding
5 forming part of a transformer having a primary winding connected to a power supply.

8. A discharge lamp according to claim 7 including a second said current control circuit connected to the other of the filaments, such that the transformer includes two said secondary windings and said primary winding connected to a power supply.

9. A discharge lamp according to any one of claims 1 to 7 including a second current
10 control circuit connected to the other of the filaments.

10. A discharge lamp according to any one of the preceding claims including a relay circuit connected to the starter circuit and at least one of the current control circuits such that: when the starter circuit is open, the relay circuit is closed to connect the current control circuit to said one filament; and when the starter circuit is closed, the relay circuit is open to
15 disconnect the current control circuit from said one filament.

11. A discharge lamp according to any one of the preceding claims including a preheat circuit to preheat the discharge lamp during a preheat period before ignition of the discharge lamp.

12. A discharge lamp according to claim 11 wherein the preheat circuit disconnects each
20 current control circuit during the preheat period thereby allowing more current to preheat the filaments, and connects each current control circuit after the preheat period.

- 29 -

13. A discharge lamp according to claim 12 wherein the preheat circuit includes a respective preheat switch connected to each current control circuit, the preheat circuit disconnecting each current control circuit during the preheat period by maintaining each respective preheat switch open during the preheat period, and connecting each current control circuit after the preheat period by maintaining each respective preheat switch closed after the preheat period.
14. A discharge lamp according to claim 13 wherein each respective preheat switch is normally-closed.
15. A discharge lamp according to claim 13 or 14 wherein the preheat circuit includes a preheat capacitor to provide power to open each respective preheat switch.
16. A discharge lamp according to claim 15 wherein the preheat circuit includes a preheat diode rectifier for rectifying a preheat current that charges the preheat capacitor.
17. A discharge lamp according to claim 16 wherein the power supply circuit provides the preheat current via the starter circuit.
18. A discharge lamp according to any one of claims 15 to 17 wherein the preheat circuit includes a discharge resistor connected in parallel across the preheat capacitor for discharging the preheat capacitor after the preheat period.
19. A discharge lamp according to any one of claims 15 to 18 wherein the preheat circuit includes a preheat diode connected in parallel across the preheat capacitor such that the voltage across the preheat capacitor is DC with suitable polarity.

- 30 -

20. A discharge lamp according to any one of claims 13 to 19 wherein each respective preheat switch forms part of a preheat relay circuit.
21. A discharge lamp according to any one of claims 11 to 20 wherein the starter circuit determines the preheat period.
- 5 22. A discharge lamp according to any one of claims 11 to 21 wherein after the preheat period a large voltage develops across the filaments to generate the lamp arc.
23. A discharge lamp according to any one of the preceding claims including a low-temperature circuit to warm up the discharge lamp in low temperature operating conditions during a warm-up period before ignition of the discharge lamp.
- 10 24. A discharge lamp according to claim 23 wherein the power supply circuit includes a capacitor, and wherein the low-temperature circuit includes a warm-up capacitor, the low-temperature circuit connecting the warm-up capacitor in parallel across the capacitor during the warm-up period thereby allowing more current to warm up the filaments, and disconnecting the warm-up capacitor after the warm-up period.
- 15 25. A discharge lamp according to claim 24 wherein the low-temperature circuit includes a warm-up switch, the low-temperature circuit connecting the warm-up capacitor in parallel across the capacitor during the warm-up period by maintaining the warm-up switch closed during the warm-up period, and disconnecting the warm-up capacitor after the warm-up period by maintaining the warm-up switch open after the warm-up period.
- 20 26. A discharge lamp according to claim 25 wherein the warm-up switch is normally-open.

- 31 -

27. A discharge lamp according to claim 25 or 26 wherein the power supply circuit provides a warm-up current via the starter circuit to close the warm-up switch.
28. A discharge lamp according to claim 27 wherein the low-temperature circuit includes a warm-up diode rectifier for rectifying the warm-up current.
- 5 29. A discharge lamp according to any one of claims 25 to 28 wherein the warm-up switch forms part of a warm-up relay circuit.
30. A discharge lamp according to any one of claims 23 to 29 wherein the low-temperature circuit includes a warm-up controller.
31. A discharge lamp according to any one of the preceding claims wherein the power
10 supply circuit includes a passive LC ballast.
32. A discharge lamp according to claim 31 wherein the discharge lamp is a T5-14W lamp and the passive LC ballast includes an inductor and a capacitor, and wherein the current control circuit includes a bypass switch connected across the capacitor, the bypass switch adapted to be open during ignition of the discharge lamp so that both the inductor
15 and the capacitor are connected, and closed after ignition of the discharge lamp so that only the inductor is connected.
33. A method of manufacturing a discharge lamp, the discharge lamp including:
a discharge tube; and
two filaments, one at either end of the discharge tube for generating a lamp arc
20 between the filaments, each filament having a first end connected to a power supply circuit and a second end connected to a starter circuit;

- 32 -

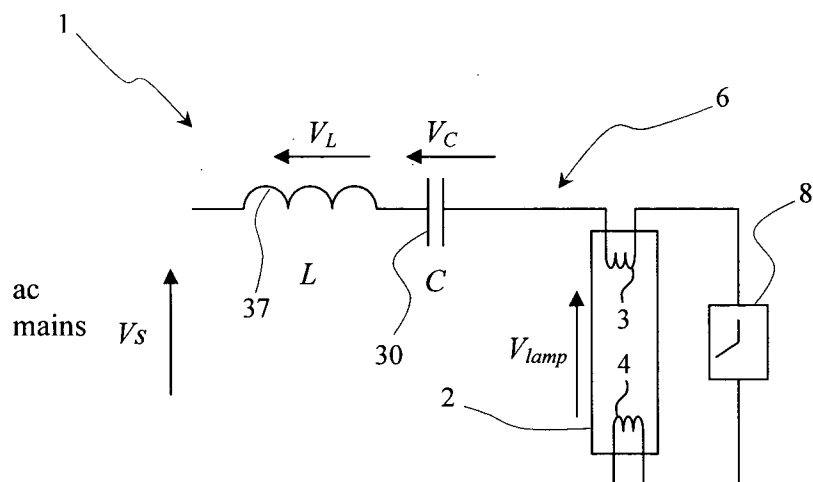
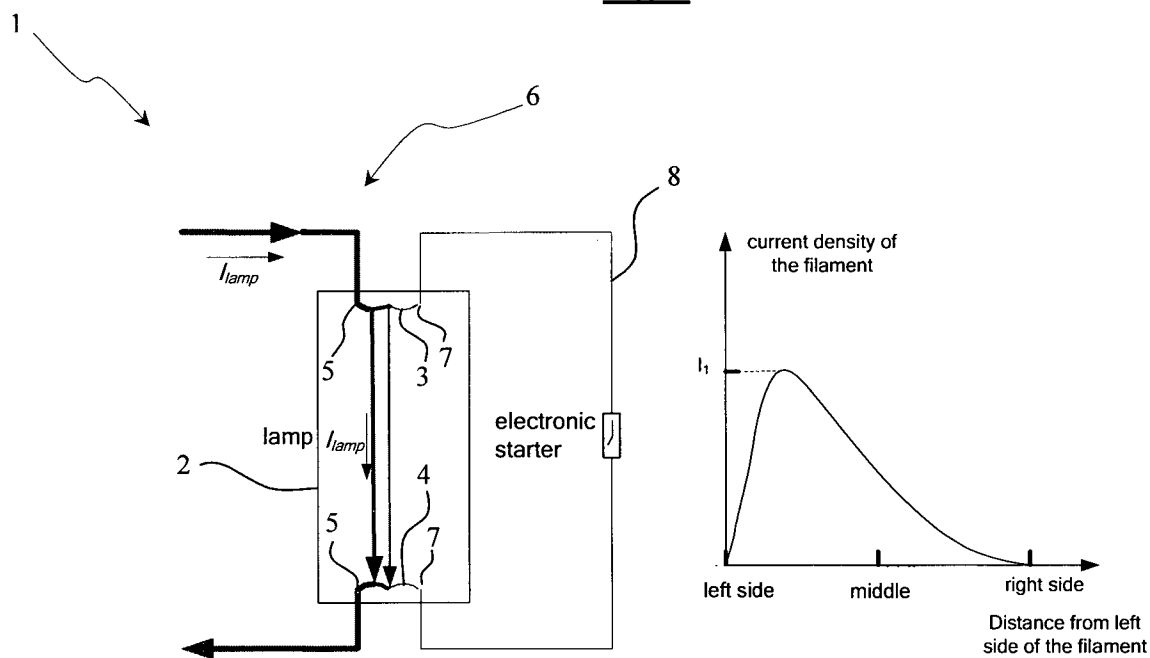
the method including the step of connecting at least one current control circuit to one of the filaments.

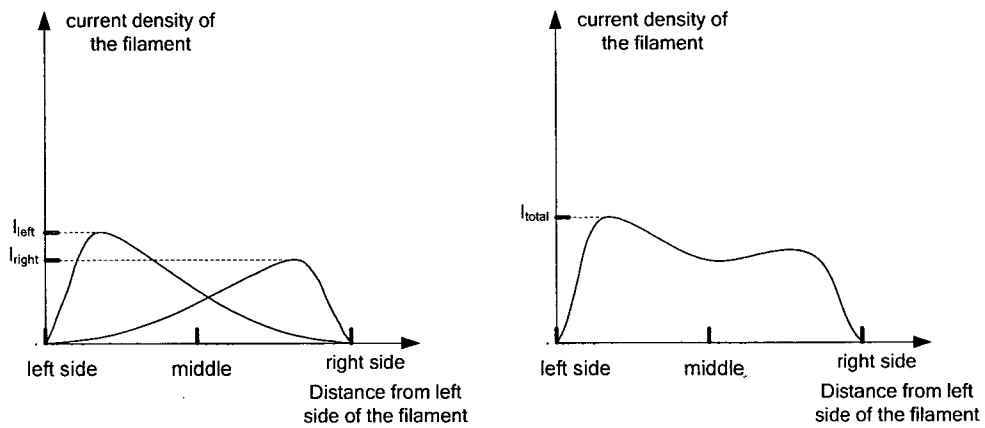
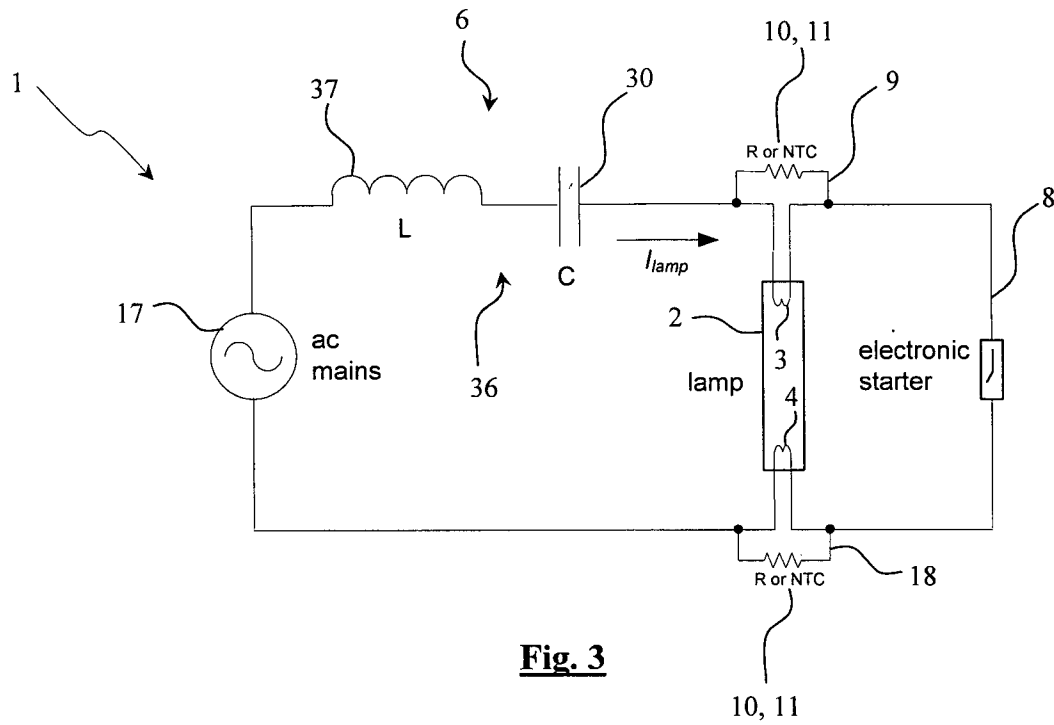
34. A method according to claim 33 including the step of preheating the discharge lamp during a preheat period before ignition of the discharge lamp.

5 35. A method according to claim 33 including the step of connecting a preheat circuit to preheat the discharge lamp during a preheat period before ignition of the discharge lamp.

36. A method according to any one of claims 33 to 35 including the step of warming up the discharge lamp in low temperature operating conditions during a warm-up period before ignition of the discharge lamp.

10 37. A method according to any one of claims 33 to 35 including the step of connecting a low-temperature circuit to warm up the discharge lamp in low temperature operating conditions during a warm-up period before ignition of the discharge lamp.

**Fig. 1****Fig. 2**

**Fig. 4**

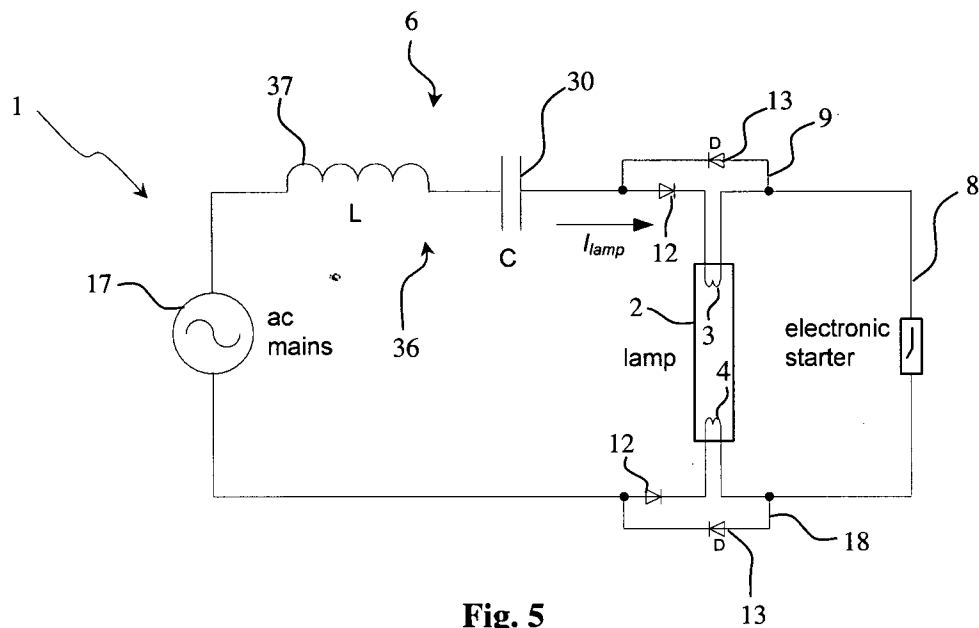


Fig. 5

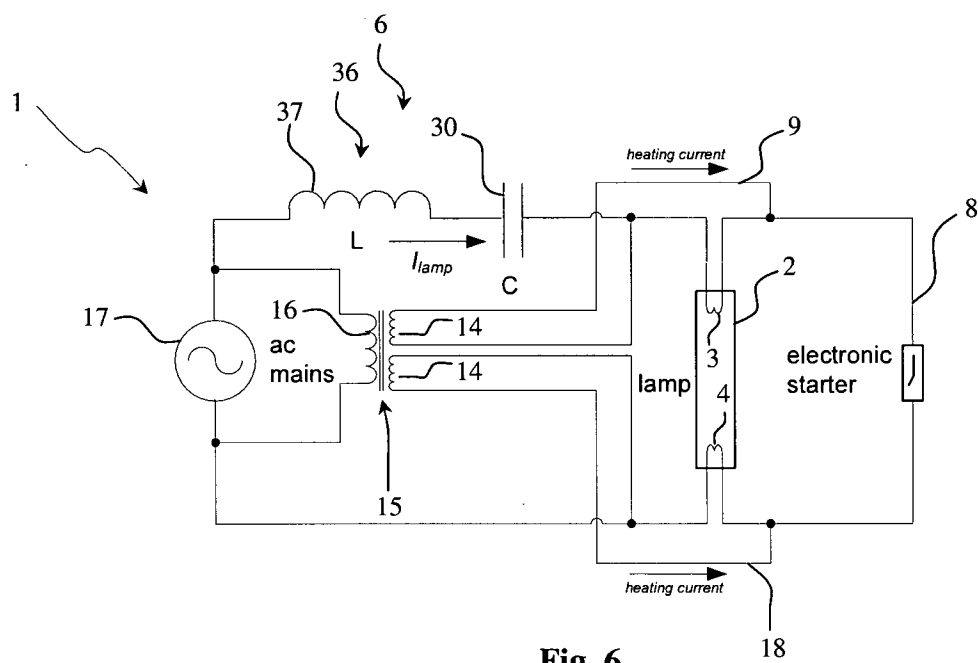
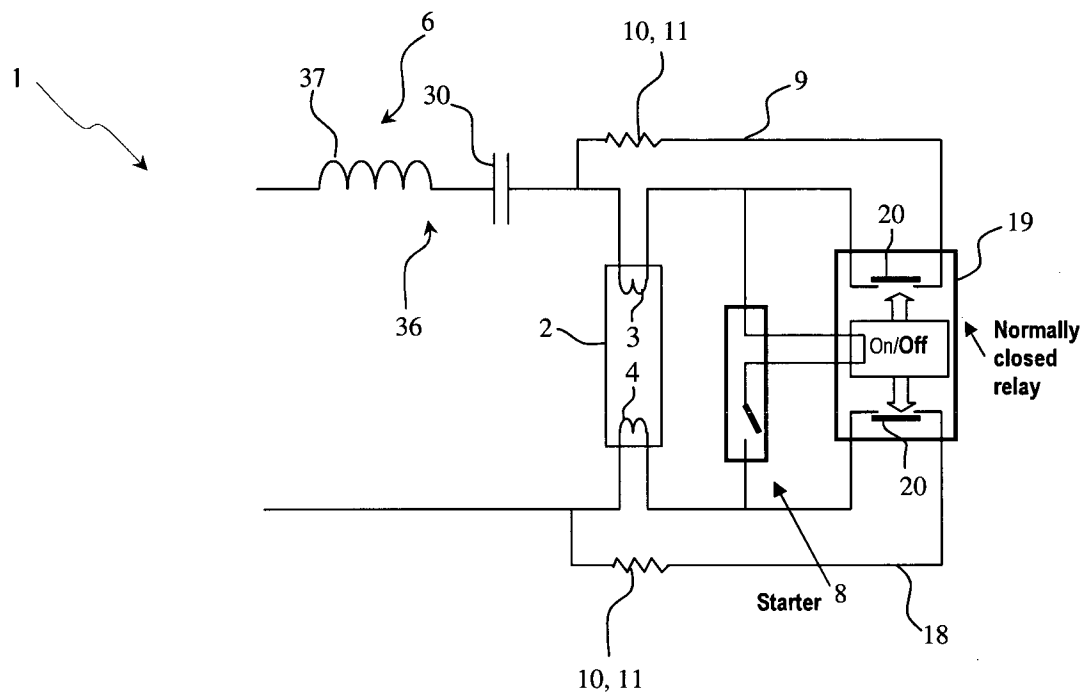
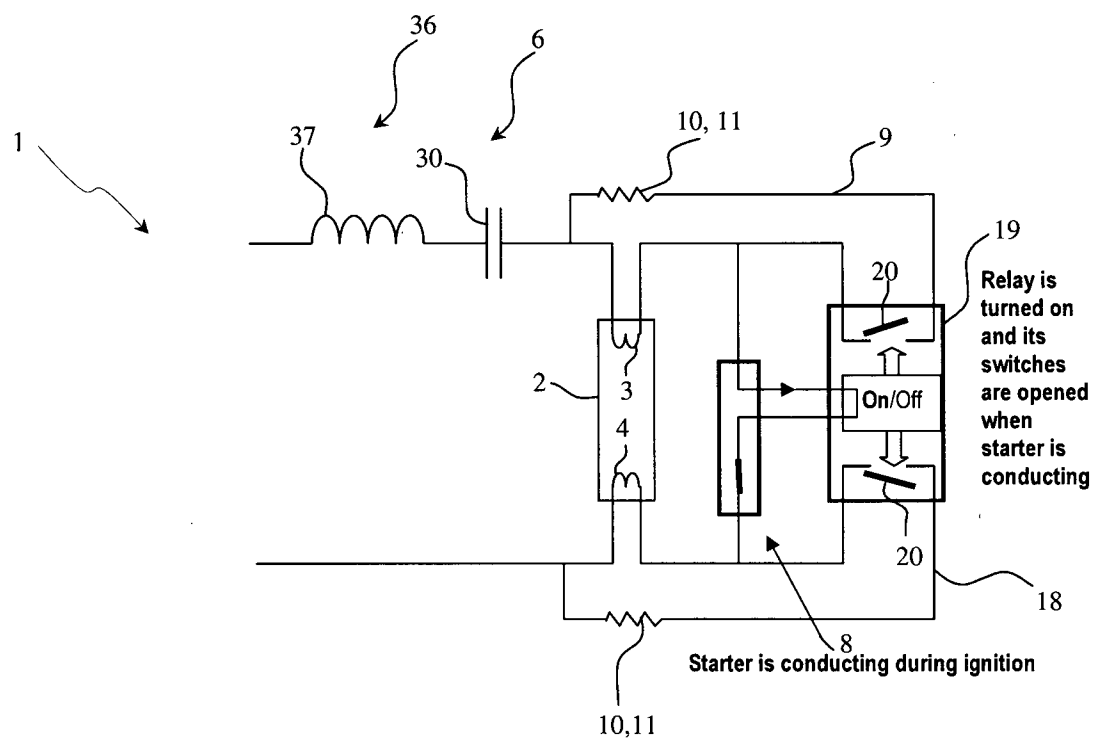
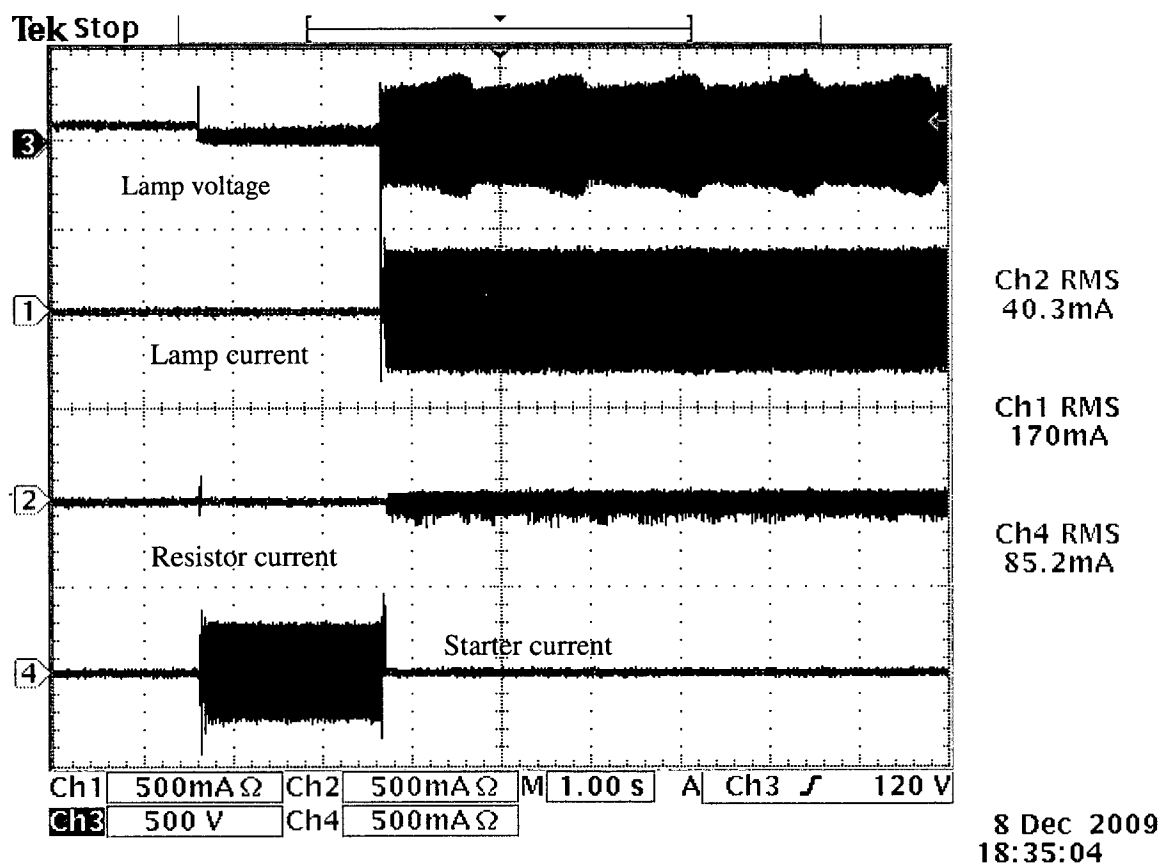
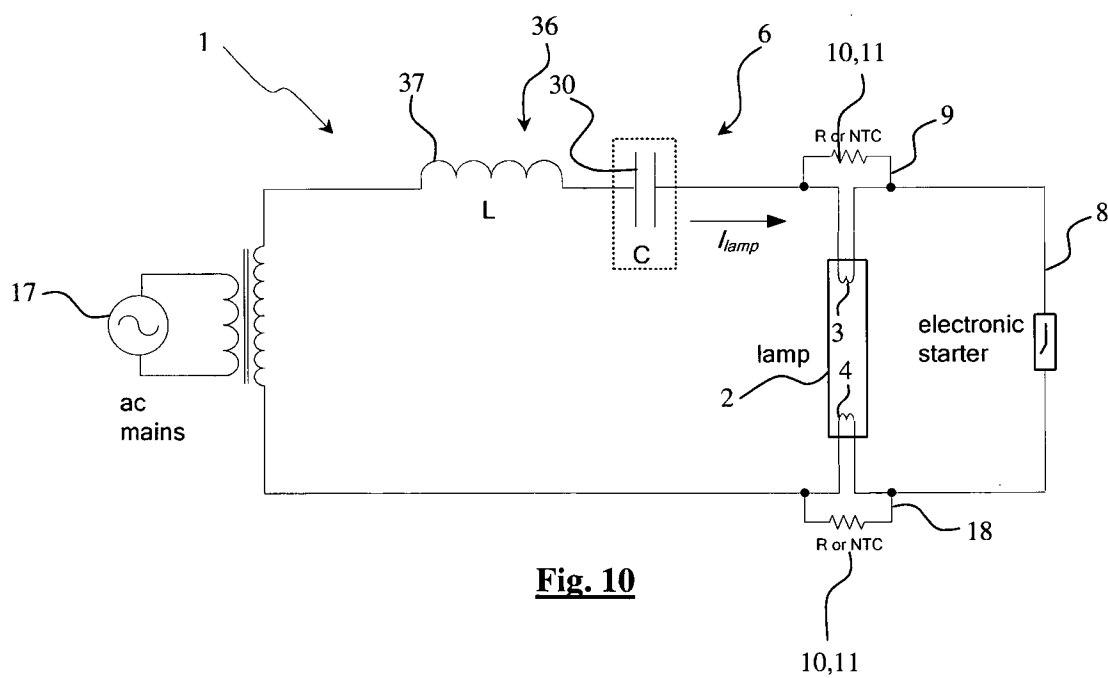


Fig. 6

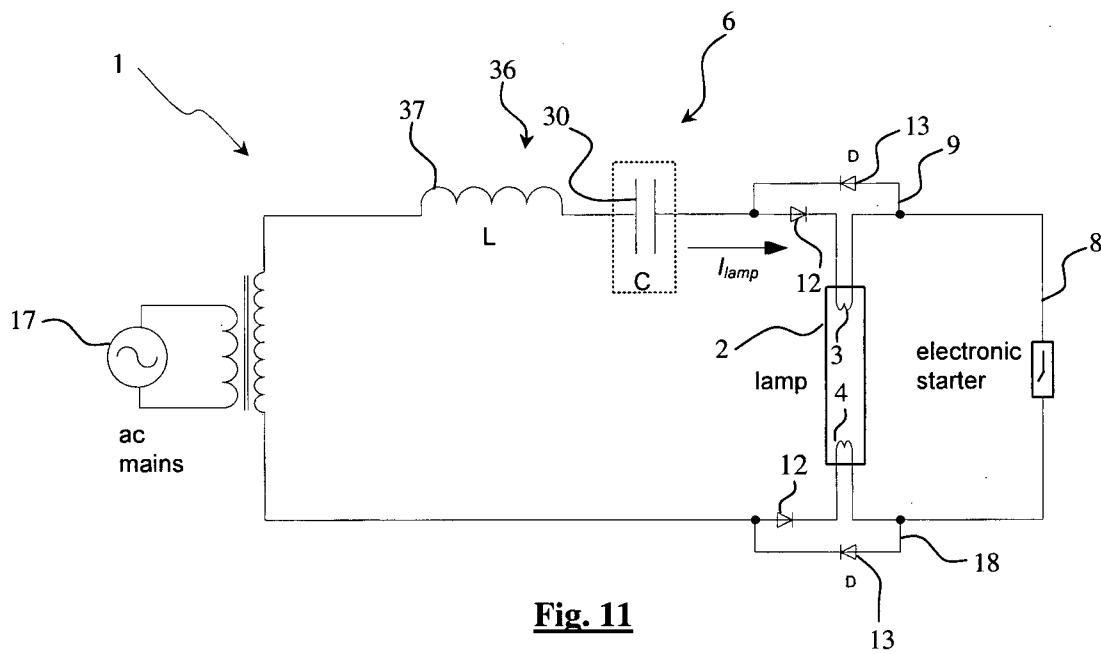
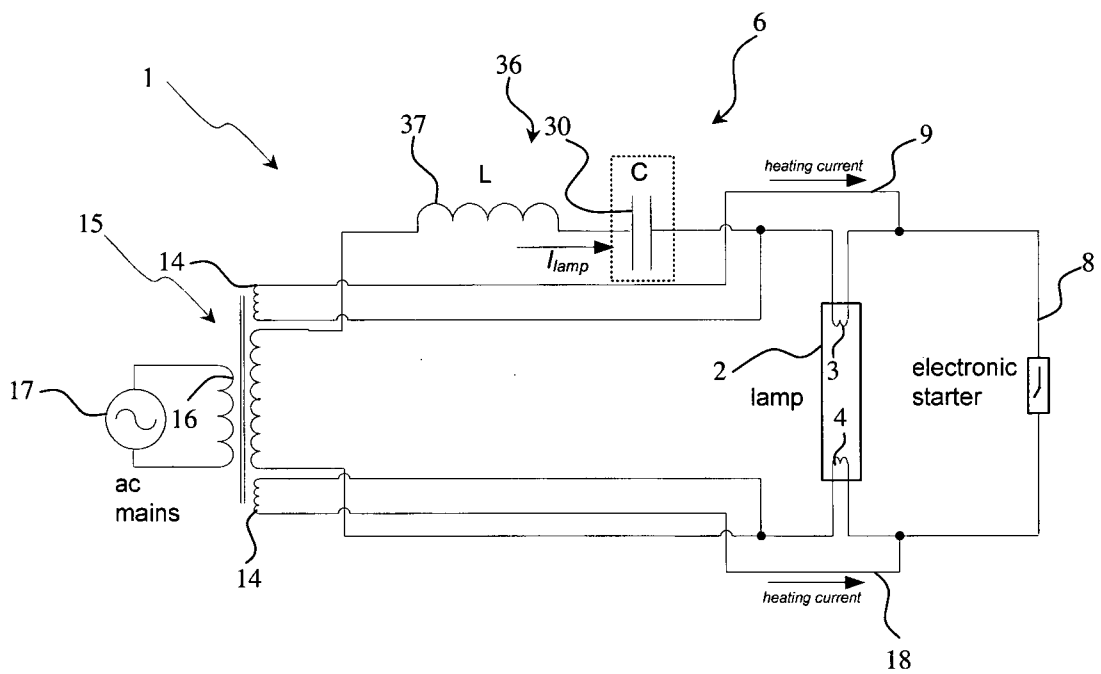
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**Fig. 7****Fig. 8**

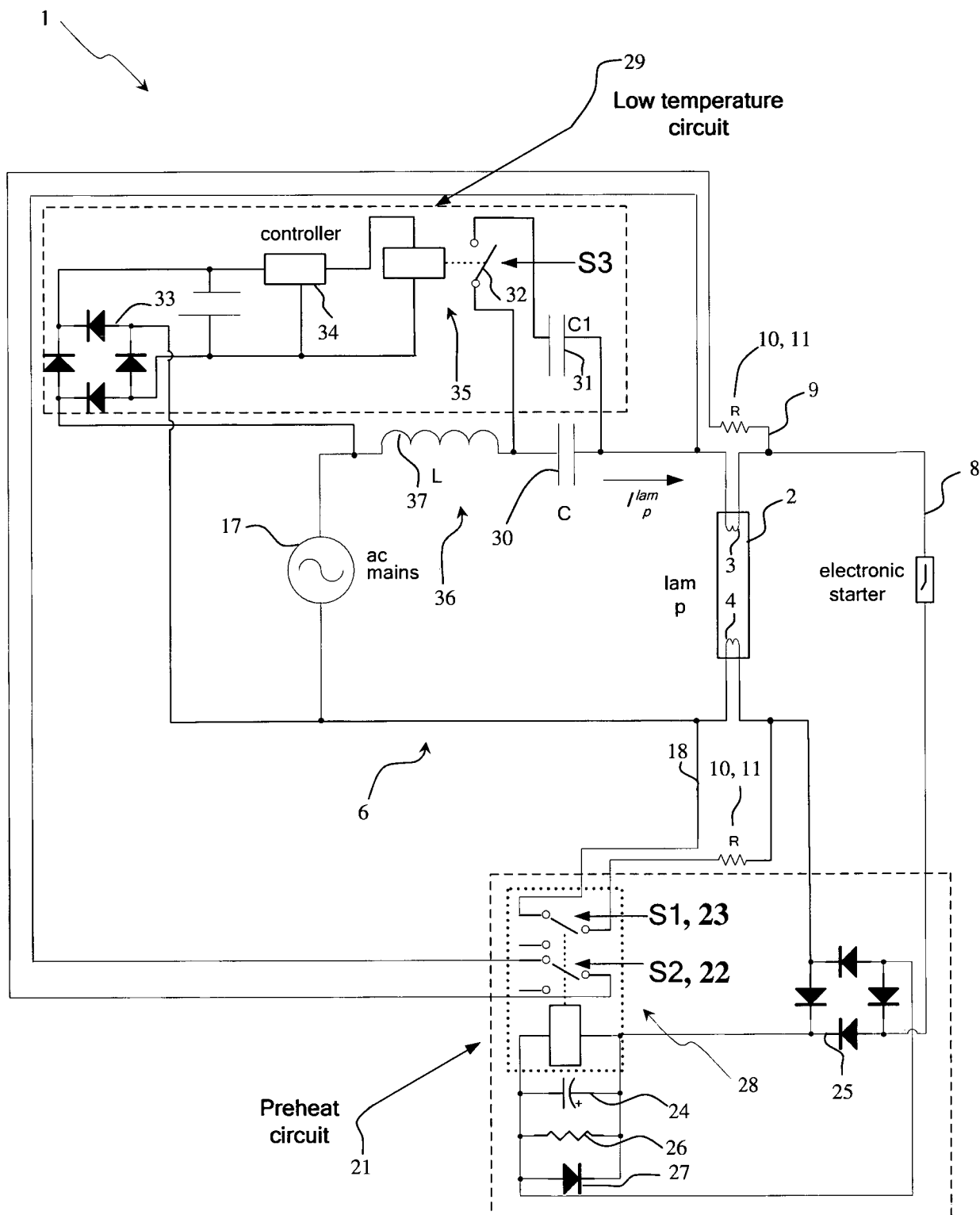
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**Fig. 9****Fig. 10**

6/10

**Fig. 11****Fig. 12**

7/10

**Fig. 13**

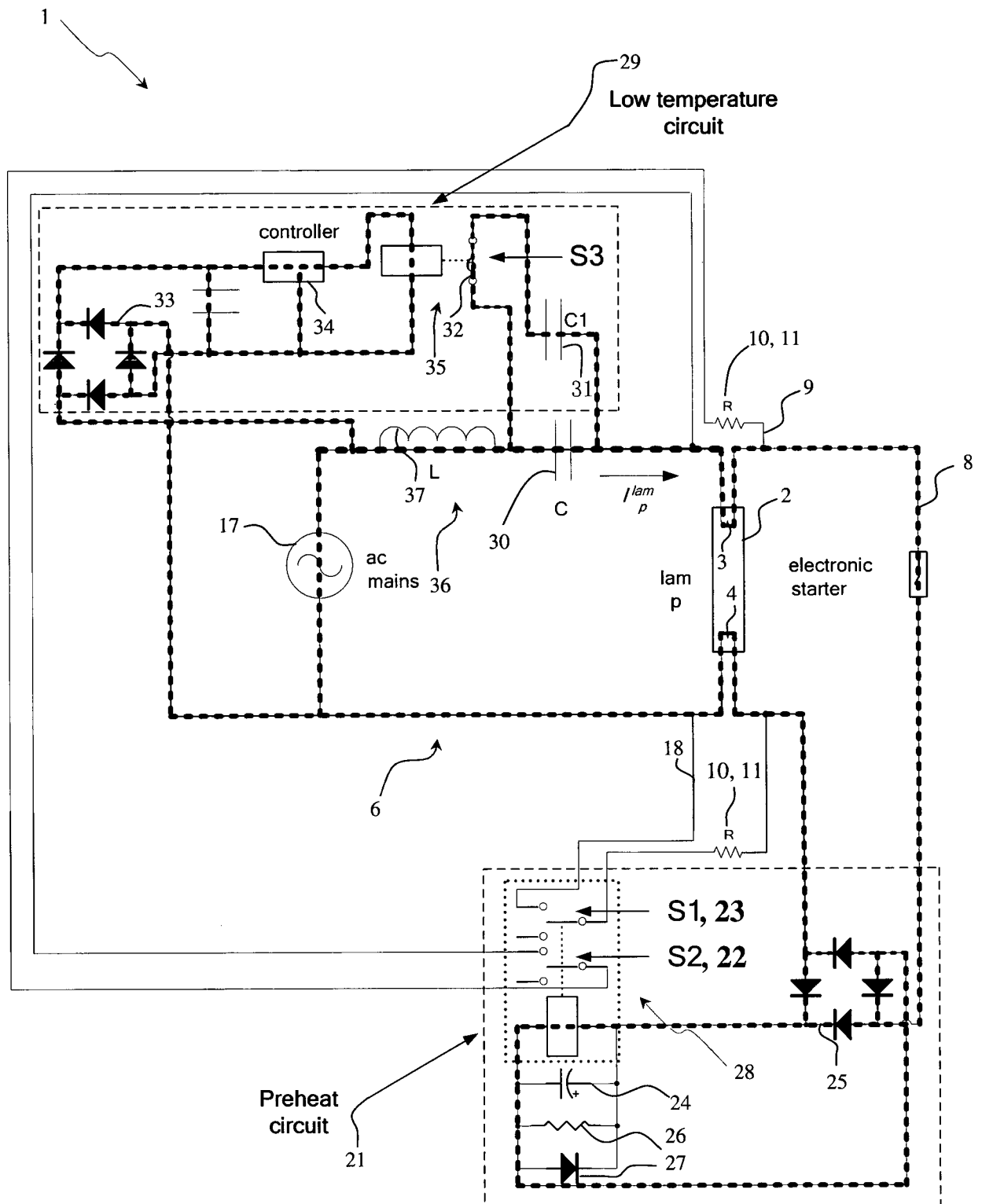
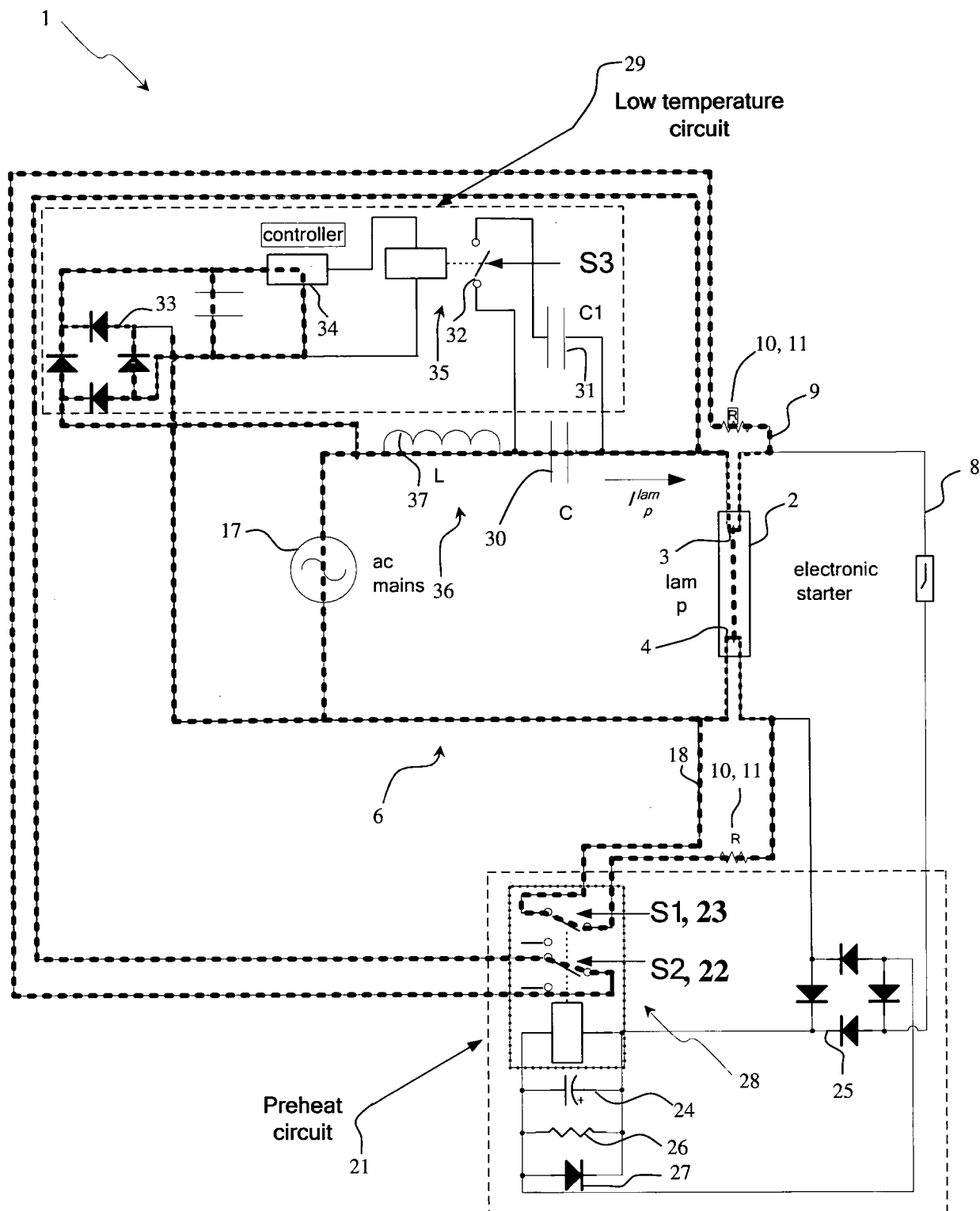
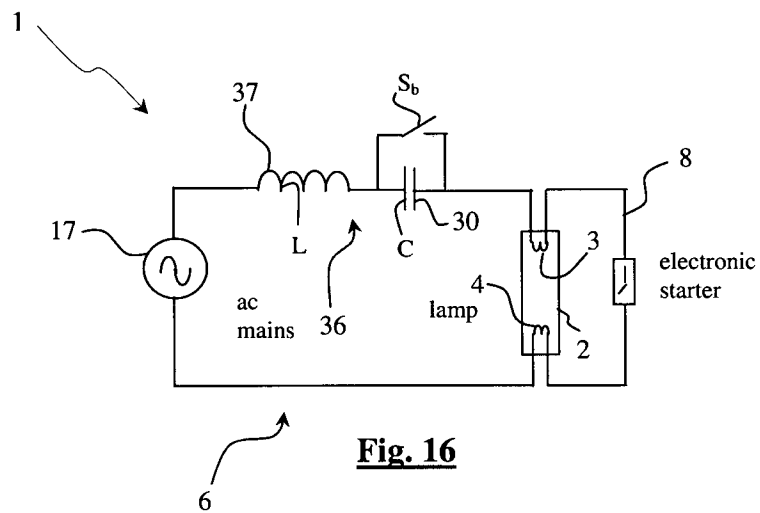


Fig. 14

9/10

**Fig. 15**

10/10



INTERNATIONAL SEARCH REPORT

International application No.

PCT/IB2011/000831

A. CLASSIFICATION OF SUBJECT MATTER

See extra sheet

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC: H05B41, H01J61

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

CNABS,CPRSABS,DWPI,SIPOABS,CNKI current , control+,limit+,bypass+, filament?, heat+,temperature,therm+, sens+, resist+, thermist+, winding?,coil?,loop?, secondary,sub,inferior+, diode?, preheat+,warm 1W up,circuit?

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CN201319691Y(FANG, Cheng), 30 Sept.2009(30.09.2009), the description page 6, line 12 to page 11, line 19, fig. 2	1-3,9,10,23-33,36,37
Y		7,8
X	CN2142257Y(WANG, Qiming),15 Sept. 1993(15.09.1993), the description pages 1-2, fig. 1	1,4,5,9,10,23-33,36,37
X	CN88200368U(YU, Weimin), 23 Nov. 1988(23.11.1988), pages 4-6, fig. 2	1,6,9-37
Y	CN1180290A(YING, Xianzhu), 29 Apr. 1998(29.04.1998), pages 1-3, figs. 2,3	7,8
X	JP2005243463A(TOSHIBA LIGHTTECH KK),08 Sept.2005(08.09.2005), pars.43-50, fig. 2	1,4,5,9,10,23-33,36,37
A	US2003/0085669A1(PAK, V. A.),08 May 2003(08.05.2003), the whole document	1-37

☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:	“T” later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
“A” document defining the general state of the art which is not considered to be of particular relevance	“X” document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
“E” earlier application or patent but published on or after the international filing date	“Y” document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
“L” document which may throw doubts on priority claim (S) or which is cited to establish the publication date of another citation or other special reason (as specified)	“&”document member of the same patent family
“O” document referring to an oral disclosure, use, exhibition or other means	
“P” document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search 06 Jan.2012(06.01.2012)	Date of mailing of the international search report 19 Jan. 2012 (19.01.2012)
Name and mailing address of the ISA/CN The State Intellectual Property Office, the P.R.China 6 Xitucheng Rd., Jimen Bridge, Haidian District, Beijing, China 100088 Facsimile No. 86-10-62019451	Authorized officer ZHU, Yucheng Telephone No. (86-10)62085563

INTERNATIONAL SEARCH REPORT

International application No.

PCT/IB2011/000831

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	US6486615B2 (UNIV HONG KONG CITY),26 Nov. 2002(26.11.2002), the whole document	1-37

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/IB2011/000831

Patent Documents referred in the Report	Publication Date	Patent Family	Publication Date
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		US7081709B	25.07.2006
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US6486615B2	26.11.2002	US2002014861A	07.02.2002

INTERNATIONAL SEARCH REPORT

International application No.

PCT/IB2011/000831

A. CLASSIFICATION OF SUBJECT MATTER

H05B 41/282(2006.01)i

H05B 41/295(2006.01)i

H01J 61/56(2006.01)i