Electrodes in discharge lamps

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The life of a discharge lamp is mainly determined by its electrodes. The electrodes also affect the luminous efficacy and the radio-frequency noise caused by the lamp. In spite of the vital significance of the chemical and physical processes associated with the operation of electrodes, however, our understanding of them is still incomplete. Some typical properties and requirements of electrodes will be considered in this article, which is largely based on the results of recent investigations in various Philips laboratories.

Function and properties of the electrodes

Most discharge lamps are operated from an a.c. voltage supply, and we shall only consider this kind of supply in this article. In a.c. operation the electrodes act alternatively as cathode and anode during each half-cycle of the mains voltage. Both electrodes thus have the same function.

The principal task of the electrode in the cathode phase is to emit electrons. In a steady-state discharge this takes place mainly by thermionic emission. The required heating of the electrode comes from ion bombardment in the cathode phase and electron bombardment in the anode phase, and also from Joule heating. Owing to electron emission, thermal conduction and radiation, heat is extracted from the electrode. During steady-state operation of the lamp the sums of the positive and negative terms are equal.

A good electrode has to meet three requirements. It must guarantee a long lamp life (this relates to the ignition of the lamp and blackening of the bulb), it must not introduce appreciable losses and it must give the minimum of radio-frequency noise. We shall now take a closer look at what this implies.

For good ignition and long life the electron emission from the electrode is important: the emitter must have a low work function, which should not be unduly increased by chemical reactions, by sputtering due to strong ion bombardment, or by evaporation. Emitter materials that have a low rate of evaporation often have a high work function, however, and this implies higher electrode losses. The first two requirements are thus contradictory, and the emitter therefore has to be chosen very carefully to meet the conditions for the particular case in question.

Because of the thermal delay of the electrodes, the electron emission during a part of the half-cycle in which the electrode functions as a cathode is greater than is necessary for the discharge current (see sections 1 and 3 of the curve in fig. 1a). This gives a negative space charge at the cathode, and this space charge limits the electron current (fig. 1b). In section 2 of the curve, however, the discharge current requires more electrons than the cathode can readily supply. As a result the negative space charge disappears and a positive electric field takes its place (fig. 1c), causing an increase in the electron emission from the cathode. With the disappearance of the negative space charge the positive ions carry a greater part of the discharge current (the difference between the lamp current and the emission current, see fig. 1a). As the space-charge region becomes thinner there is less chance that the ions will lose the energy they have taken up in the cathode fall by collision with gas atoms, and they are therefore able to give up more energy to the electrode. Thus, the higher the value of the electron bombardment to which the electrode is subjected. While a low ion bombardment may have an activating effect on electron emission — by improving the desirable physico-chemical properties of the cathode surface [1] — heavy ion bombardment seriously impairs the quality of the electrode by causing sputtering of the emitter material. In this connection the method of igniting a discharge lamp is important. In fluorescent

![Fig. 1.](attachment:fig1.png)

**Fig. 1.** a) Schematic waveform of the lamp current in a half-cycle of the supply voltage. $I_e$ electron-emission current from the cathode. $I_1$ ion current. b) Voltage variation in front of the cathode as a function of distance $x$ during the parts 1 and 3 of the lamp current curve, in which a negative space charge is built up due to surplus emission. There is hardly any ion bombardment of the cathode. c) Voltage variation in part 2 of the lamp-current curve, where the emission is intensified by an electric field. In this situation the cathode is subject to the strongest ion bombardment.

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lamps the electrodes are briefly preheated to facilitate ignition. SOX lamps and high-pressure lamps, on the other hand, are ignited with cold electrodes. In this case there is a heavy ion bombardment at first, which is greatly reduced as soon as the electrode reaches the temperature at which electrons are emitted. The electrodes therefore have to be designed to reach a high temperature quickly.

Electrode losses arise because heat is lost from the electrode by radiation, conduction in the electrode itself and conduction into the gas. Low losses are obtained with low electrode temperatures, which means that a low work function is required. The losses depend to a great extent on the geometry of the electrode [2]. To reduce heat conduction a small wire diameter must therefore be used, and although small dimensions give higher temperatures and hence greater radiation losses, the net effect — particularly with electrodes in high-pressure lamps — is a reduction of the losses. Since unduly high temperatures may impair the stability of the emitter, however, the dimensions of the electrode must be chosen in such a way that the heat supplied to the electrode — mainly in the anode phase — ensures a temperature level at which there is just the right amount of electron emission in the cathode phase.

Although a periodic negative space charge (fig. 1a, sections 1 and 3 of the curve) prevents heavy ion bombardment of the electrode, it also constitutes a source of radio-frequency noise [3] — the ‘re-ignition-extinction noise’ — at frequencies in the region of 500 kHz, which often occurs in fluorescent lamps. The reason for this is that the space charge forms a potential well in which positive ions enter into oscillation (fig. 1b), and it is these oscillations that cause the noise. If the emission is reduced on this account, however, the life of the electrode is shortened by the resultant heavier ion bombardment.

Another form of radio interference, caused by anode oscillations, occurs when the active part of the electrode during the anode phase is too small to accumulate sufficient electrons. The anode potential then rises above that of the plasma (anode fall). The effect of this is to accelerate the electrons, causing additional ionization of gas atoms, with the result that the density of the electron current increases and the anode accumulates sufficient electrons. The anode potential then drops again to that of the plasma, and the cycle is repeated. The radio interference arises at these drops in anode potential.

The above brief description of possible causes of radio-frequency noise, which have recently been investigated, makes it clear that the composition and operation of the electrodes are important. A study of these effects [4] has shown that one way in which radio noise can be greatly reduced is to surround the electrodes with a cylindrical metal grid [5].

We shall now consider the various points raised here in a more detailed examination of the different kinds of electrodes used in discharge lamps.

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Low-pressure discharge lamps

The electrode in the fluorescent lamp is a coil of tungsten wire coated with an emitter (fig. 2). The emitter consists of a mixture of oxides, mainly of Ba, Sr and Ca. The coating is applied by means of a suspension of carbonates which are converted into oxides by heating the coil during the lamp-manufacturing process:

\[ \text{MCO}_3 \rightarrow \text{MO} + \text{CO}_2, \]

where M stands for Ba, Sr and Ca. This involves the following important subsidiary reaction:

\[ 3\text{MCO}_3 + \text{W} \rightarrow \text{M}_3\text{WO}_6 + 3\text{CO}. \]

The tungstate is important for the life of the electrode. It forms a layer between the oxides at the surface and the tungsten coil and regulates the production of free barium. The presence of free barium at the surface is necessary for a low work function. It can be formed from the reaction

\[ 6\text{BaO} + \text{W} \rightarrow \text{Ba}_3\text{WO}_6 + 3\text{Ba}, \]

and possibly also by the dissociation of BaO by ion bombardment.

The tungstate layer must have the right thickness and the right structure. If the layer is too thin or the structure too open, barium production will be excessive. As a result the barium quickly evaporates — so that barium spots form on the bulb wall near the electrode — and the electrode is very soon exhausted. If the layer is too thick or the structure too dense, barium production will be too low. This increases the work function, and the temperature of the electrode is then increased as a result of heavier ion bombardment, giving faster evaporation and sputtering. If the carbonate causes too much oxidation of the tungsten, there is a risk that too much oxygen will be released in the lamp during operation, resulting in the gradual formation on the wall of a light-absorbing layer consisting mainly of oxides of mercury.

Since the life of the electrode is partly determined by the amount of emitter, as much emitter material as possible must be stored in a suitable manner. A ‘triple-coiled’ filament is commonly used for this storage (see fig. 2): around the tungsten filament, which is itself a double helix (coiled coil) a third coil S of very thin wire is included to improve the cohesion between oxide and tungsten base [6].

While the lamp is operating, the emission and collection of electrons do not take place uniformly over the whole surface of the electrode. A small bright spot in the filament appears at the place where the density of the emission current during the cathode phase is much greater than elsewhere. During the life of the lamp the position of this ‘hot spot’ usually shifts. During the anode phase the majority of the electrons arrive at the connection end of the filament.

The electrode losses differ from one type of lamp to another. The voltage drop at the electrodes, \( V_{el} \), is generally about 15 V. The losses are then given by \( V_{el}I \) and amount to about 6 W in the case of a 40-W fluorescent lamp.

The electrode in a low-pressure sodium (SOX) lamp, shown in operation in fig. 3, is generally required to supply a higher current than the electrode in a fluorescent lamp, and is therefore more rugged in construction. Its design is optimized for cold ignition. The emitter is the same as that on the fluorescent-lamp electrode, but in this case it is applied by electrophoresis. The electrode losses are 12 or 18 W, depending on the lamp current (0.6 or 0.9 A).

High-pressure discharge lamps

The electrode in high-pressure lamps is usually in one of the forms shown in figs. 4 and 5. Differences are found only in the case of electrodes in lamps for very low or very high powers. The electrode in fig. 4, which is used in high-pressure mercury (HP) and high-pressure sodium (SON) lamps consists of a tungsten rod \( W \) with a tungsten coil \( S \) wound around it in two layers. The emissive material is stored in the space between the turns, and consists in this case of BaCO\(_3\), CaCO\(_3\) and ThO\(_2\). It has been found that ThO\(_2\) acts as an emitter when the lamp is operating. The BaCO\(_3\) and CaCO\(_3\) are converted into Ba\(_2\)CaWO\(_6\) during sintering; this tungstate is active on ignition. The emitter mixture used in the low-pressure lamp is not suitable for high-pressure lamps.
for high-pressure lamps, because the high gas temperature in such lamps (3000-6000 K) would make the electrode so hot, because of conduction, that the emitter would very quickly evaporate. ThO₂ evaporates much more slowly under these conditions, but the work function is higher.

In the HP lamp, as in the fluorescent lamp, a hot spot forms on the electrode. The end of the electrode has a temperature of about 2000 K, and the temperature at the hot spot is a few hundred degrees higher. In the SON lamp, on the other hand, the temperature profile is more homogeneous. The electrode temperature in this lamp is lower: 1800 K. This difference is probably due to the presence of a little sodium on the electrode surface, which plays an important role in the emission.

The electrode losses depend to a great extent on the geometry of the electrodes. A different electrode is required for each of the nine types of HP lamp with power ratings from 50 to 2000 W. The losses in the HP 400-W lamp are 30 W, in the SON 400-W lamp they amount to 24 W.

The metal-iodide (HPI) lamp uses a different type of electrode. This consists of a tungsten rod, around which a single coil S₁ is first wound, followed by a smaller coil S₂ wound in two layers in the space between the rod and S₁. One reason for using this geometry is to prevent iodides from condensing on the electrode during the cooling of the lamp after switching off, which would interfere with the ignition later. The presence of iodine also explains why alkaline-earth oxides cannot be used for the emitter; they react too readily with iodine. The ThO₂ also used as emitter in this type of lamp has been found to meet the requirements, though it is only active during ignition. The temperature at the end of the electrode coil is 3000 K, from which it follows that the tungsten is the emissive material. The electrode losses in a 375-W lamp amount to 36 W.

Finally, not even ThO₂ can be used in the tin-halide lamp, owing to its high reactivity with the chlorine gas present. So far tungsten has proved to be the only material that is reasonably resistant to such a reactive gas filling. The electrode temperature and losses are of the same order of magnitude as those in an HPI lamp.

It should be noted, incidentally, that tungsten can be used as an emitter in both these halide lamps because the presence of the halogen ensures that the tungsten evaporated and sputtered from the electrode is not deposited on the wall.

Continued research on electrodes for discharge lamps is expected to lead to a further reduction of the losses in SOX lamps, as opposed to the fluorescent lamps, where the limits for the improvement of losses and life appear to have been reached. In the case of the high-pressure lamps there are good prospects for the work on the improvement of the emitters and the reduction of losses.

Summary. The operation and properties of electrodes in discharge lamps are described, with particular reference to their influence on lamp life, energy losses and radio noise. Electrode design and choice of emitter must be adapted to the conditions so that the electrode is sufficiently resistant to ion bombardment during the cathode phase. The causes of radio noise are briefly discussed. The article concludes with a description of some types of electrode used in low-pressure lamps (fluorescent, SOX) and in high-pressure lamps (HP, HPI).