Osmium dispenser cathodes

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It might reasonably be expected that metals of low work function would be most suitable in the development of dispenser cathodes, when high emission current density or low operating temperature are required. This turns out, perhaps unexpectedly, not to be the case. Very promising results have now been achieved with less common metals such as rhenium or ruthenium, and, in particular, with osmium.

A characteristic of dispenser cathodes, such as the “L” cathode and the impregnated cathode, is that a functional distinction exists between the emissive surface and a reserve supply of the material that serves to keep the work function of the emissive surface sufficiently low. One possible arrangement for an L cathode is illustrated in fig. 1. The emission from a cathode of this type takes place from the surface of a porous tungsten body (the substrate), whose work function is lowered by adsorbed Ba and BaO (the adsorbate). Behind the tungsten body the L cathode has a storage chamber which contains a mixture of tungsten powder and barium-calcium-aluminate of composition 5BaO.3CaO.2Al2O3. The structure of an impregnated cathode is somewhat different: there is no storage chamber and the barium-calcium-aluminate is adsorbed in the pores of the porous tungsten body. In the barium-calcium-aluminate, which is found to consist of three phases, i.e. Ba3Al2O6, Ba2CaAl2O6 and CaO, a chemical reaction takes place at the operating temperature of the dispenser cathodes, probably in accordance with the equation:

\[ W + 3\text{Ba}_{2}\text{Al}_{2}\text{O}_{6} + 6\text{CaO} \rightarrow 3\text{Ba}_{2}\text{CaAl}_{2}\text{O}_{6} + \text{Ca}_{3}\text{WO}_{6} + 3\text{Ba} \]  \hspace{1cm} (1)

and this ensures an adequate supply of barium to the emissive surface.

The metallic character of these cathodes and the presence of a sufficiently large reserve of activating material make them particularly useful for applications which require a combination of long life and heavy current densities — for continuous as well as pulsed operation — and good mechanical properties.

Fig. 1. Basic construction of an L cathode. 1 porous tungsten body. 2 chamber containing a reserve supply of barium-calcium-aluminate. 3 molybdenum cylinder. 4 filament.

The development of microwave tubes, such as disc-seal triodes, klystrons and magnetrons for higher and higher frequencies and output powers has benefited from these characteristics of dispenser cathodes, and has in its turn stimulated further investigations into these cathodes. Dispenser cathodes are also being used with success in many other types of thermionic valve. In all cases, however, the valves have been for professional applications.

Dispenser cathodes have not so far been used in non-professional valves for various reasons. Most important among these are the relatively high price, the high operating temperature (1110 °C) and, for some applications, the excessive evaporation of the activating material (Ba and BaO).

[3] This has been demonstrated by C.A.M. van den Broek and A. Venema in this laboratory. Having regard to recent investigations, we feel justified in assuming the validity of equation (1) for the reaction.

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These factors are to some extent interrelated. The high operating temperature of 1110 °C inevitably entails expensive methods of mounting the filament. In order to achieve good heat transfer and at the same time sufficient electrical insulation it is necessary to cement the filament of an L cathode into the molybdenum cylinder (3 in fig. 1). This is a rather costly operation. The high operating temperature required is also responsible for a rapid evaporation of the activating material. Again, the development of a cheaper dispenser cathode (the pressed cathode 14) was hampered by this evaporation. In this type the cathode body is made of compressed tungsten powder and barium-calcium-aluminate. Efforts were made to reduce excessive evaporation in these cathodes by using mixtures of tungsten and molybdenum powders, at the expense, however, of the permissible current density, as the work function of the cathodes was increased by the addition of molybdenum.

In these considerations it is seen that attempts to widen the useful applications of dispenser cathodes must be concentrated on lowering the operating temperature.

The dependence of the current density $j$ of a thermionic cathode on the temperature $T$ is given by Richardson's equation:

$$j = AT^2 \exp \left(-\frac{e\Phi}{kT}\right), \quad \ldots \ldots \ldots \quad (2)$$

where $\Phi$ is the work function of the cathode surface, $e$ the electron charge, and $k$ is Boltzmann's constant. The factor $A$, which is in theory $120 \text{A/cm}^2\text{deg}^2$, is for various reasons much smaller in practice, but little can be done to improve it. If, therefore, one wishes to achieve a specified thermionic current density at a lower operating temperature, the work function has to be reduced.

If this can be done, it is then also possible to increase the current density if required, while maintaining the operating temperature at the same value. This again may be useful for certain applications in professional valves.

**Possible ways of reducing the work function**

The work function of the surface of a conductor is governed by two parameters: the chemical potential $\mu_e/e$ of the electrons in the conductor, and the electrostatic potential barrier $\varphi_a$ at the surface [6]:

$$\Phi = -\mu_e/e - \varphi_a, \quad \ldots \ldots \ldots \quad (3)$$

The first of these two parameters, $\mu_e$, depends only on the chemical composition of the conductor. The second parameter, $\varphi_a$, is determined in the first place by the surface structure, i.e. for a given metal, by the choice of crystal plane, but it is also dependent on external influences, in our case on the presence of foreign ions on the surface.

Modification of the potential barrier $\varphi_a$ by means of adsorbed ions is a traditional method of reducing the work function of cathodes. The adsorbate used may for example be caesium, barium, lanthanum or thorium. For normal oxide cathodes Ba is used — here not adsorbed on a metal but on an oxide of an alkaline earth metal; dispenser cathodes also use Ba(BaO), adsorbed on a substrate of polycrystalline tungsten. For every combination of adsorbate and substrate there is an optimum degree of surface coverage at which the work function reaches a minimum value.

In order to lower further the work function of our dispenser cathodes, one might choose a different adsorbate or a different substrate. It has been found that in practice a different adsorbate does not lead to better results. Although Cs(Cs2O) lowers the work function more than Ba(BaO), it is not as a rule suitable for use in thermionic valves because of its high volatility: this would so reduce the maximum permissible temperature of the cathode that the emission density would drop to a lower value than found with a Ba(BaO) layer.

However, unexpected results have been obtained at Philips Research Laboratories in Eindhoven through the use of a different substrate. These results depend on the paradoxical fact that the *effective work function* [6], given an optimally covered surface, is smaller for a higher work function of the non-covered substrate. This was predicted on theoretical grounds [7] and was later confirmed by extensive theoretical and experimental investigations with caesium as adsorbate [8].

We shall here explain this unexpected result by means of a highly simplified model. We shall then deal in more detail with the results obtained with dispenser cathodes in which the substrate is osmium instead of tungsten.

**Work function theory based on a simple model**

Fig. 2 shows the potential curve at the surface of the emissive body, the surface being assumed to be homogeneous (i.e. without atomic structure). We assume

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[6] A different choice of materials generally changes the factor $A$ in the Richardson equation (2). To make it possible to compare cathodes at a given temperature, it is usual to calculate from the measured $j$ the value of $\Phi$ for $A = 120 \text{A/cm}^2\text{deg}^2$. This value is called the effective work function. See e.g. E. B. Hensley, J. appl. Phys. 32, 301, 1961.
Fig. 2. Potential curve at the surface of an emissive body. As is customary, the graph shows the positive direction of the potential downwards. \( F \) Fermi level. \( O \) potential level in vacuum. \( \Phi_0 \) work function.

(a) Without adsorbate. \( C \) is the lower limit of the conduction band in the metal. For \( \mu \) see eq. (3).

(b) With a certain quantity of adsorbate. The adsorbed atoms give rise to donor levels \( D \) which are at a potential difference \( \phi_{\text{ads}} \) below the local potential \( P \). The work function has been reduced from \( \Phi_0 \) to \( \Phi \).

(c) With optimum coverage. The level \( D \) coincides with the Fermi level. The work function has the minimum value, \( \Phi_{\text{min}} \).

For simplicity that all the electrons in the metal are at the Fermi level \( F \); at a considerable distance away they are at the vacuum level \( O \). The potential difference which the electrons have to overcome with the aid of thermal energy in order to leave the metal — the work function — is denoted by \( \Phi_0 \) for the case where there are no adsorbed ions (fig. 2a). The values of \( \mu \) and \( \phi_0 \) are here taken into account (see eq. 3). The value of \( \phi_0 \) is now altered by the adsorption of atoms able to give up electrons to the metal — thus acting as a kind of surface donor. In fact the ions formed at the surface, together with their mirror image charge, effectively form a charged capacitor, so that the total potential curve has the form shown in fig. 2b. This lowers the work function by an amount \( A\phi \).

How far can this process of adsorption and lowering of \( \Phi \) continue? If only one atom is adsorbed it gives rise to a donor level which is lower than the local potential (as yet unchanged) by an amount which we shall call \( \phi_{\text{ads}} \). If this donor level is higher than the Fermi level, an electron will as a rule be given up to the metal. As the number \( N \) of adsorbed ions per unit area increases (all at a distance \( r \) from the ideal surface) the local potential decreases — causing a decrease of \( \Phi \) — and consequently the height of the donor level above the Fermi level also decreases (fig. 2b). There will no longer be any ionization, and thus the process of adsorption with ionization and lowering of \( \Phi \) cannot continue, as soon as the level of the donors coincides with the Fermi level. In this situation — the optimally covered surface — where \( N_{\text{opt}} \) ions are adsorbed and the local potential at \( r \) is lowered to a height \( \phi_{\text{ads}} \) above the Fermi level, we have the lowest work function, \( \Phi_{\text{min}} \); see fig. 2c.

In reality the nature of the process gradually changes before we reach this stage, because the surface coating contains an increasing fraction of non-ionized donors, and moreover the effect of the adsorption on the potential curve gradually decreases — or even changes sign — because to a certain extent the adsorbed ions can form dipoles. All these factors can however be disregarded in our model.

Consider now a different substrate, which has a higher work function \( \Phi_0 \) in the uncoated state. The same considerations can be applied in this case. Although \( \phi_{\text{ads}} \) and \( r \) depend slightly on the substrate, their influence can be neglected. Here also, for an optimally covered surface, the local potential at the location \( r \) will have dropped to a height \( \phi_{\text{ads}} \) above the Fermi level. If we try to draw a continuous potential curve that passes through this fixed point and through the starting point, located at the metal surface, which is at a height \( \Phi_0 \) above the Fermi level (fig. 3), we see that the final level, at a considerable distance from the surface, will naturally be smaller if the starting point is made higher. A substrate with a higher \( \Phi_0 \) therefore gives a lower \( \Phi_{\text{min}} \). This is the paradoxical effect already mentioned. Its explanation, using the picture we have sketched, is that the number of ionized donors providing the optimum coverage, \( N_{\text{opt}} \), rises with increasing \( \Phi_0 \) to such an extent that the increase of \( \Phi_0 \) is more than compensated.

Fig. 3. Starting from a higher \( \Phi_0 \) (\( \phi_{\text{ads}} > \phi_0 \)), a lower \( \Phi_{\text{min}} \) (dashed curve) may be expected when the surface is optimally covered.
A rough calculation based on the model yields expressions for \( N_{\text{opt}} \) and for the final work function \( \Phi_{\text{min}} \), which lead to the same conclusion.

The calculation is as follows. If there are \( N \) ionized atoms present per unit area, then the potential at the surface with respect to that at a considerable distance is increased by:

\[
\Delta \Phi = \frac{1}{\varepsilon_0} N e r.
\]

In fact, if we have a parallel-plate capacitor with vacuum dielectric and a spacing between the plates of \( \varepsilon \), the potential at the surface with respect to the plane of symmetry is given by eq. (4) if the charge per unit area is \( N e \). The local potential at the location of an ion can be calculated by assuming that the ion has a circular area \( \pi d^2 \) available to it (by definition of \( N, \pi d^2 N = 1 \)), while all other adsorbed ions are distributed homogeneously over the rest of the surface. This is a plausible simplification in view of the migration of the adsorbed ions. The homogeneously distributed ions, together with their mirror image, again form a parallel-plate capacitor with a spacing between the plates of \( \varepsilon \), but in which there is now a circular hole of diameter \( 2d \). It can be shown by a simple calculation that, at the location of the ion, in the centre of this hole, there must be a potential difference with respect to the metal surface, of magnitude:

\[
\Delta \Phi = N \left( \sqrt{\pi d^2 + 4\pi^2 r^2} - d \right) e/2\varepsilon_0,
\]

or, as \( \pi d^2 N = 1 \):

\[
\Delta \Phi = \sqrt{\pi N \left( \sqrt{1 + 4\pi^2 r^2} - 1 \right)} e/2\varepsilon_0.
\]

We have seen that the optimum ion coverage, \( N_{\text{opt}} \), is reached as soon as the local potential has dropped to the height \( I_{\text{ads}} \) above the Fermi level. Therefore:

\[
\sqrt{\pi N_{\text{opt}} \left( \sqrt{1 + 4\pi^2 r^2 N_{\text{opt}} - 1} \right)} e/2\varepsilon_0 = \Phi_0 - I_{\text{ads}}.
\]

On the other hand, we then have according to eq. (4):

\[
\Delta \Phi_{\text{max}} = \Phi_0 - \Phi_{\text{min}} = N_{\text{opt}} \varepsilon_0 / e\Phi_0.
\]

By eliminating \( N_{\text{opt}} \) from (6) and (7) we find the relation of interest between \( \Phi_{\text{min}} \) and \( \Phi_0 \):

\[
\Phi_0 - I_{\text{ads}} = \sqrt{e(\Phi_0 - \Phi_{\text{min}}) / 4\pi^2 e^2} \left( \frac{1}{e} \left( \Phi_0 - \Phi_{\text{min}} \right) - 1 \right).
\]

It is easily verified that, provided the condition \( \Phi_0 > I_{\text{ads}} \) is fulfilled, \( d\Phi_{\text{min}}/d\Phi_0 \) is in fact negative — and this is the paradoxical effect mentioned above.

Still keeping to our model, \( \Phi_{\text{min}} \) can easily be calculated for the case where \( N_{\text{opt}} \) is still fairly small, so that the ions cover only a small part of the metal surface. In this case the expression between brackets in eq. (6) is approximately \( 2\pi^2 N_{\text{opt}} \), and eq. (8) simplifies to:

\[
\Phi_{\text{min}} = \Phi_0 - \sqrt{e(\Phi_0 - I_{\text{ads}})^2 / 4\pi^2 e^2}.
\]

For a caesium adsorbate we put \( r = 1.65 \times 10^{-10} \) m and \( I_{\text{ads}} = 3.87 \) volt, which are the values for the free caesium ion and the ionization potential of the free caesium atom. We may then expect that, because of the condition referred to, a negative \( d\Phi_{\text{min}}/d\Phi_0 \) will arise in metals for which \( \Phi_0 > 3.87 \) V. On the other hand, eqation (9) can only be applied to metals for which \( \Phi_0 < 5.1 \) V; at greater \( \Phi_0 \) the value of \( N_{\text{opt}} \) is so high that the approximation used is no longer sufficiently accurate.

As an example we can use the equations to calculate \( \Phi_{\text{min}} \) for the adsorption of caesium on two different tungsten surfaces: a (100) plane and a (112) plane. For the (100) plane we have \( \Phi_0 = 4.65 \) V \([9]\). With the values of \( I_{\text{ads}} \) and \( r \) for caesium the equations yield:

\[
N_{\text{opt}} = 9.25 \times 10^{13} \text{cm}^2 \quad \text{and} \quad \Phi_{\text{min}} = 1.88 \text{ V}.
\]

For the tungsten (112) plane a higher value of \( \Phi_0 \) applies:

\[
4.85 \text{ V} \quad \text{and the equations give:} \quad N_{\text{opt}} = 1.08 \times 10^{14} \text{cm}^2 \quad \text{and} \quad \Phi_{\text{min}} = 1.63 \text{ V}.
\]

That is to say a substantially lower work function.

Although, in view of the nature of the model, the calculations only have a qualitative significance, these results do not, remarkably enough, differ very much from the values found by experiment. If they are to be compared, it should be noted that only the total quantity of adsorbate can be determined experimentally, i.e. the sum of ionized and non-ionized donors, whereas \( N_{\text{opt}} \) relates only to the ionized ones. The ratio between the two quantities when the surface is optimally covered can be calculated on a statistical basis; for caesium it is \( 1:2 \), so that for the two cases we find from the calculated values of \( N_{\text{opt}} \) a total occupation of \( 2.8 \times 10^{14} \text{cm}^2 \) for the (100) plane of tungsten and \( 3.2 \times 10^{14} \text{cm}^2 \) for the (112) plane. In recent measurements \([10]\) on a polycrystalline tungsten surface, which had been thermally etched before the adsorption of caesium the minimum work function found was \( \Phi_{\text{min}} = 1.78 \pm 0.01 \text{ V} \), the adsorption amounting to 2.6 to 2.8 \( \times 10^{14} \) atoms/cm\(^2\).

**Measurements on various substrates using a barium adsorbate**

Much less is known experimentally about the way in which the work function of the substrate affects the resultant work function when Ba(BaO) is used as adsorbate instead of caesium, nor is it possible to calculate \( \Phi_{\text{min}} \) for barium from the purely ionogenic model used, as the value to be inserted for \( I_{\text{ads}} \) is not known. However, investigations by Rittner \([11]\) on tungsten and molybdenum, and by Sackinger and Brodie \([12]\) on rhenium, gave analogous results: here also \( \Phi_{\text{min}} \) is found to decrease with increasing \( \Phi_0 \).

On the basis of the foregoing, we have investigated various metals to determine their usefulness as a substrate for dispenser cathodes. The choice of these metals was dictated by the requirements that the work function in the uncoated state should be higher than \( 4.54 \) V, the work function of tungsten, and that the metals should not alloy with Ba, nor react with the barium-calcium-aluminate mixture used as the filling in dispenser cathodes.

Rhenium, ruthenium, iridium and osmium are metals that meet these requirements. The work function of polycrystalline rhenium is 5.1 V. The work functions of
polycrystalline iridium and osmium have been found in our laboratory [13] to have values of $5.50 \pm 0.05$ V and $5.93 \pm 0.05$ V, respectively. The work function of ruthenium is not known exactly but is in any case higher than that of tungsten. These four metals were applied in layers between 0.1 to 1 μm thick to the porous tungsten body of a dispenser cathode, which in other respects was made in the normal way, either as an L cathode or as an impregnated cathode. The pores of the tungsten have dimensions of the order of 10 μm, so that the thinly applied metal coating in no way inhibits the replenishment process in the dispenser cathode.

As expected, after adsorption of Ba(BaO) the effective work function decreased as the work function of the substrate increased. The differences found between dispenser cathodes using Re, Ru, Ir and Os were not very considerable. The work function of the cathodes coated with osmium, however, was plainly the lowest. We therefore constructed a number of osmium-coated cathodes and subjected them to various extensive tests.

Osmium-coated cathodes

Current density

Fig. 4 shows the current density as a function of temperature for an L cathode with 0.5 μm thick osmium coating and for a normal L cathode. The measurements were made with a simple diode with an anode-cathode spacing of 0.4 mm, at an anode voltage of 1000 V and under pulsed loading, the pulse length being 50 μs and the repetition frequency 50 pulses per second. It can be seen from the figure that at 800 °C the current density of the Os cathode is about 10 times higher than that of an uncoated cathode. At 1050 °C the current densities still differ by a factor of 2.5. It can also be seen that the osmium cathode needs a temperature 100 °C lower than that of a normal L cathode for the same current density.

Calculation of the work function from the curves gives $\Phi = 1.60$ V and a value of $A = 10 \text{ A/cm}^2\text{deg}^2$ for the Os cathodes, compared with $\Phi = 1.95$ V and $A = 50 \text{ A/cm}^2\text{deg}^2$ found for the uncoated cathodes.

More detailed information on the emission characteristics of an Os cathode and a normal L cathode is given in fig. 5. In this figure the abscissa represents the effective work function at 800 °C (i.e. the $\Phi$ value calculated for $A$ assumed at 120 $\text{A/cm}^2\text{deg}^2$ [10]), and the ordinate gives for each value of $\Phi_{\text{eff}}$ the fraction of the total cathode surface at which that value is found. It is seen that the average $\Phi_{\text{eff}}$ for the Os cathode is 1.68 V and that for a normal L cathode 1.90 V. An-
other feature of note in the graph is the reduced spread in the work function of the Os cathode. This feature can be important in valves in which the emitted electrons should as far as possible have the same energy.

**Life**

The life of an L cathode is proportional to the quantity of barium-calcium-aluminate in the storage chamber. For a given porosity of the tungsten body, the quantity of Ba (and BaO) lost by evaporation per unit time and per unit cathode surface depends only on the cathode temperature (fig. 6). The life of a normal L cathode operating at 1110 °C is in the region of 15 000 hours. An osmium-coated cathode with the same reserve supply of barium-calcium-aluminate may be expected to have the same life if operated at 1110 °C; if, however, the Os cathode is operated at a temperature of 1010 °C, which is sufficient for the same emission, the cathode should have a 6 to 10 times longer useful life.

Two series of cathode life-test experiments have been started to check this prediction, using Os cathodes of 8 mm² surface area, with 0.5 μm osmium, mounted in diodes with molybdenum anodes and operated at 100 mA, i.e. 1.3 A/cm², at a cathode temperature of 1110 °C in one series and at 1010 °C in the other. These experiments have now been in progress for 14 000 hours — there are unfortunately only 9000 hours in the year. During this time the saturation emission has remained virtually constant. This means that the advantage of the lower operating temperature has been brought into effect; whether the extremely long life predicted will be achieved in these experimential valves is not yet known. In fact, it is conceivable that the osmium coating will eventually disappear as a result of evaporation, diffusion or migration. Nothing of this has yet been noticed at temperatures lower than 1050 °C, even with the thinnest coatings of 0.1 μm. At temperatures higher than 1150 °C, however, there are some indications of coating loss. A separate series of tests has been started to investigate this effect as a function of cathode temperature and coating thickness, but these tests will take a considerable time to complete because of the long lifetimes involved.

Osmium-coated impregnated cathodes are more subject to coating loss. At a cathode temperature of 1110 °C the “osmium properties” have disappeared after only about 5500 hours of operation, and the cathode then behaves in the same way as an uncoated impregnated cathode. At a cathode temperature of 1060 °C this happens after about 7500 hours, but at a temperature of 1010 °C this type of cathode also shows no signs of osmium loss, even after 14 000 hours.

The exhaustion of the reserve of barium-calcium-aluminate, which we have mentioned as the primary cause of limitation of life, is of course not the only possible cause. The filament may break, the porous tungsten body may become deformed, the valve characteristics may be affected by the evaporated Ba and BaO (insulation faults, grid emission). At the lower operating temperature of the osmium cathodes, all these factors as well will only make their effect felt after a much longer running time than with normal L cathodes.

**Secondary electron emission**

In some applications, for example in magnetrons, the contribution of the secondary electron emission to the total current density is very important. Although no particular attention was paid to this point in the development described here, it is nevertheless a welcome incidental feature that the secondary emission coefficient of the osmium-coated cathodes is appreciably higher than that of normal dispenser cathodes. It is worth noting that in this respect as well, osmium is by far the most suitable of the metals investigated.

In fig. 7 the results of measurements of the secondary emission coefficient are presented as a function of the energy of the primary electrons, for an osmium-coated L cathode, for a normal L cathode and for a normal impregnated cathode. Although the differences in the secondary emission coefficient are evidently not very large, they are nevertheless important. In a 4 mm magnetron type DX 164, for example, the maximum current density is 190 A/cm² with an uncoated impregnated cathode, but 320 A/cm² with an Os cathode.
Other practical data

As shown in the foregoing, the reduction in the temperature required for operation increases the possibility of using dispenser cathodes in non-professional valves, where the expense of initial purchase and replacements is such an important consideration. The development of such applications is still in the initial stage. As indicated, however, the new cathodes with their higher performance may also be useful in various professional valves, in particular in microwave valves. We have already mentioned magnetrons. The use of Os cathodes is also being investigated in disc-seal triodes [14] and in various reflex klystrons.

In the disc-seal triodes osmium-coated cathodes are under test both at 1150 °C (the usual temperature for uncoated cathodes in these tubes) and at 1020 °C. In both cases the cathode loading is 0.75 A/cm² and up to now the useful life is longer than 10 000 hours. Because of the low barium evaporation and the imperceptibly small deformation of the tungsten body, the valve characteristics, particularly for cathodes operated at 1020 °C, are remarkably constant compared with those of valves with uncoated cathodes. From these data the expected life of Os cathodes at an operating temperature of 1020 °C (970 °C black-body temperature) may be estimated at several times 10 000 hours — more than sufficient for valves to be used in interplanetary missions.

The use of Os cathodes makes it possible to make reflex klystrons for even shorter wavelengths than have up to now been possible. Normal uncoated L cathodes have a reasonably long life in continuous operation at loadings up to 8 A/cm². This is just sufficient, as B.B. van Iperen has shown, for a 2 mm reflex klystron to be feasible [15], albeit with marginal characteristics. Using an Os cathode, G. H. Plantinga of this laboratory has succeeded in producing a practical 2 mm reflex klystron (type DX 247) in which the current density is 20 A/cm². With the same type of cathode he was also able to develop a 1.5 mm reflex klystron. In this case continuous loading at about 25 A/cm² is required.


Summary. To widen the useful scope of dispenser cathodes, the work function of the emissive tungsten surface should be reduced to a value lower than that already achieved with the coating of adsorbed barium. This has been made possible by the paradoxical effect that the work function of a metal surface optimally covered with barium is lower for a higher work function of the uncoated metal. This effect is explained with the aid of a simple model, and by means of an approximate calculation equations are derived for estimating the work function to be expected. The predictions are found to agree very reasonably with experiments. With a view to the practical application of the effect, dispenser cathodes were made with the porous tungsten body variously coated with a thin layer (0.1 to 1 μm) of rhenium, ruthenium, iridium or osmium. The best results, i.e. a lowering of the work function from 1.95 V to 1.60 V, were obtained with osmium. This means that an osmium-coated L cathode operated at 800 °C has a current density 10 times higher than a normal L cathode. This improvement can be utilized either for operating the cathode at a lower temperature, thus making more economical designs and longer lifetimes possible (e.g. in disc-seal triodes several times 10 000 hours) or for achieving even higher current densities (e.g. 25 A/cm² in a 1.5 mm reflex klystron).