ELECTRON EMISSION FROM OXIDE COATED FILAMENTS

By Lewis R. Koller

Abstract

Emission from oxide coated filaments.—(1) *Effect of various gases.* Platinum iridium filaments were coated with oxides of Ba and Sr by repeatedly dipping in a solution of the nitrates and burning in a CO_2 atmosphere. Under good vacuum conditions the emission corresponds to the equation $I = aT^2e^{-b/T}$ where $a = .00107$ amp/cm^2 and $b = 12{,}100$ deg. for the filaments studied. The presence of oxygen in small amounts (10^{-3} mm) decreases the emission ten to a thousand fold, depending on the temperature, while argon, hydrogen, CO and CO_2 cause a great increase. These results indicate that the emission is due not to the oxides but to a film of metal. (2) *Positive ion bombardment* also increases the emission, probably by reducing some of the oxide. (3) *Flashing at 1600°K* for 1 to 5 min. de-activates the filament, but heating at lower temperatures (900°K) restores the activity. (4) *Distribution of initial velocities* was found to follow Maxwell's law, but the average energy came nearly 30 per cent higher than that corresponding to the temperature of the filament.

ELECTRON emission from the oxides of the alkali earths was first studied by Wehnelt in 1904. He found that a small amount of CaO on platinum gave a very high emission and this type of cathode has since been known as the Wehnelt cathode. Subsequently, the emission from such cathodes was studied by Richardson and in more recent years by Arnold, Davisson and Germer, Wilson and others.[1]

Some irregularities observed by the writer in the behavior of Wehnelt cathodes led to an investigation of the effects on them of various gases. It was found that under high vacuum conditions very uniform results are obtained, while very small traces of gas may produce considerable changes in emission.

The filaments used consisted of a platinum iridium core (10 to 15 percent iridium) 9 mils (.22 mm) wide by 0.25 mil (.006 mm) thick on which was deposited a coating of the oxides. The method of applying the coating was to dip the wire into a solution containing respectively three percent of barium nitrate and two percent of strontium nitrate and then burn it for a few seconds at a high temperature in an atmosphere

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[1] W. Wilson, Phys. Rev. **10**, 79 (1917);
C. Davisson and H. A. Pidgeon, Phys. Rev. **15**, 553 (1920);
H. D. Arnold, Phys. Rev. **16**, 70 (1920);
Davisson and Germer, Phys. Rev. **15**, 330 (1920).

of carbon dioxide. This process was then repeated until the coating reached the desired thickness. About 40 cycles were usually sufficient.

Such a coating consists largely of the carbonates, as can readily be demonstrated by dipping a filament in hydrochloric acid, which results in a rapid evolution of gas. This evolution of gas takes place even after a filament has been burned for several hundred hours.

The filaments were mounted in tubes with cylindrical nickel anodes and given a condensation pump exhaust. During exhaust the bulb was baked out for at least an hour at 360°C. The anode was then heated by high frequency induction to drive out occluded gases, and the filament was flashed at 1350°K for 15 minutes. The tube was then immersed in liquid air and measurements made while the pump was running. (In some cases instead of a nickel anode a film of tungsten was deposited on the walls of the bulb by the evaporation of a tungsten filament and this was used as an anode.) Measurements of emission were then made at various filament temperatures.

EFFECTS OF GASES

When the values of log (i/T^2) are plotted against $1/T$, a straight line results (as in Fig. 1) showing that the emission obeys the equation $i=aT^2e^{-b/T}$. The constants determined from this line are

$$a=1.07\times10^{-3} \text{ amp. per sq. cm}; \; b_o=12{,}100 \text{ deg.}$$

Temperatures were found from the relation between temperature and resistance determined for an uncoated strip by Dr. H. A. Jones of the Research Laboratory at Schenectady.

If a small pressure of oxygen (5×10^{-3} mm) is now introduced into the tube and the values of i/T^2 are again measured and plotted against $1/T$ a curve such as the lower one of Fig. 1 results. The emission still obeys the same law as before but the constants a and b have both increased to the values

$$a=4.27\times10^{3}; \qquad b=35{,}900.$$

While a has increased over 100,000 fold, the increase in emission due to the increase in a is more than counterbalanced by the decrease in emission due to the increase in b so that the emission of the filament in oxygen is less than that in vacuum. It can be seen from the figure that at high temperatures the curves would cross and the emission in the presence of oxygen would be higher than in vacuum. At these temperatures however, the rate of evaporation of the oxides is so high that the filaments cannot be operated.

On pumping out the oxygen the slope of the curve remains unchanged while the value of a increases slightly until pressures of the order of 10^{-4}

mm are reached. Below this pressure the changes are rather erratic, but by pumping and burning the filament at normal operating temperature, it can be restored to its initial condition. Unless the last traces of oxygen are pumped out, no heat treatment alone can restore the emission.

If a filament is burned at sufficiently high temperatures to evaporate the oxides and determinations of a and b_0 are made at frequent intervals, it is found that the values tend to pass from those observed in vacuum to those observed in oxygen.

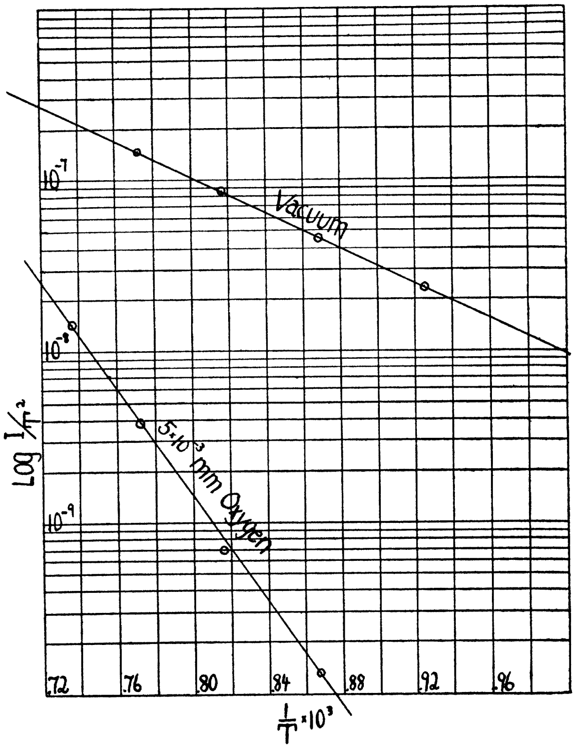

Fig. 1. Log (i/T^2) as a function of $10^3/T$.

The foregoing results indicate that the emission is due, not to the oxides, but to a film of metal, and anything which tends to destroy this film either by evaporation or by oxidation destroys the emission.

Water vapor has the same effect as oxygen in "poisoning" the emission. In the presence of gases such as argon, carbon dioxide, carbon monoxide or hydrogen, the emission is increased by a factor of from 10 to 100 depending upon the history of the filament. This increase is due to an increase in a while b_0 remains practically constant. Conditions in these gases are difficult to reproduce and reliable quantitative data have not been obtained.

Effects of Positive Ion Bombardment

It is found that when a filament is operated under conditions such that positive ion bombardment can take place, that is, with a small amount of residual gas present and an anode voltage greater than the ionizing voltage, the emission is always greatly increased. The increase may become permanent and remain even after the gas has been removed. The positive ion bombardment seems to have the effect of reducing some of the oxide to the metal, which is necessary in order to get a high emission. This increase in emission is actually due to a change produced in the nature of the surface, and is not due to secondary emission, for, as Davisson and Germer[1] have shown, the number of secondaries per positive ion is never very large. Bombardment by positive ions, however, can change the nature of the surface from one having a low primary emission to one having a high primary emission. For example, a filament which gave a saturation emission of 1.9 milli-amp. in a good vacuum gave an emission of over 20 milli-amp. at a pressure of 0.5×10^{-3} mm of carbon dioxide.

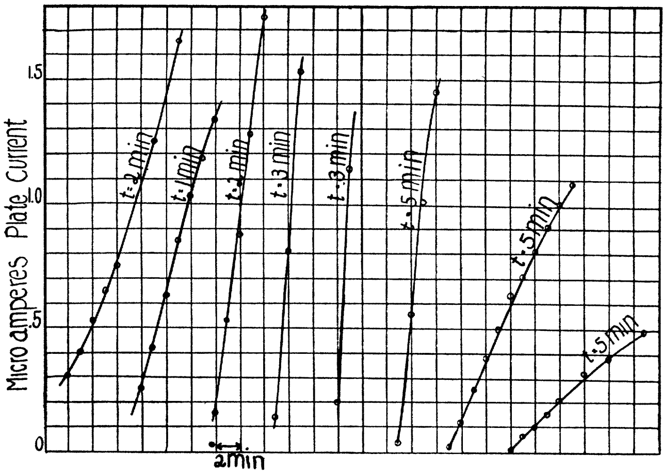

Fig. 2. Curves showing re-activation of filament at 900°K after burning at 1600°K for 1 to 5 minutes.

Effects Due to Temperature

While the active material may be produced in part by positive ion bombardment it is also produced by the effect of the temperature at which the filament is operated. This is shown by the curves of Fig. 2.

The filament was partially de-activated by burning at 1600°K for a short interval. The temperature was then dropped to 900°K and the rate of re-activation measured. The values of emission were then plotted against time as shown in the figure. A series of such activation curves was taken for various periods of flashing at the high temperature. From the figure it can be seen that the rate of activation increases with the time of flashing at the high temperature, passes through a maximum and then decreases. The explanation is that "active" material is formed at the high temperature but the rate of evaporation is too high to permit it to remain on the surface. At lower temperatures the surface becomes partially covered by some of the material which diffuses from inside the oxide coating. The rate at which the surface becomes covered depends on the concentration within the coating. This increases with the length of time of flashing up to the point where further flashing results in more "active" material being lost by evaporation than is formed. This is analogous to the phenomena observed in the case of thoriated filaments, which have been described by Dr. I. Langmuir.[2] In the case of oxide coated filaments, however, sufficient active material may be present initially so that it is not necessary to use the temperature treatment.

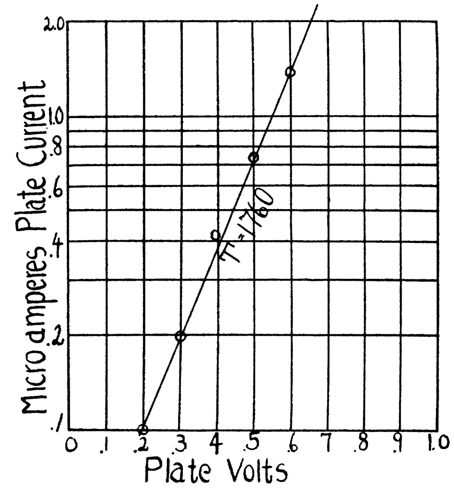

Fig. 3. Log i as a function of plate voltage, showing that distribution of initial velocities of electrons is Maxwellian.

Initial Velocities

Measurements of initial velocity of the emitted electrons were made to see whether the velocity distribution followed Maxwell's distribution

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[2] Langmuir, Phys. Rev. **22**, p. 357, 1923.

law. The procedure used consisted in measuring the space current with low retarding and accelerating voltages on the plate. The values of log i when plotted against V gave a straight line as shown in Fig. 3, showing that the distribution obeys Maxwell's law. The average value of the kinetic energy of the emitted electrons calculated from this curve corresponds to 1760°K which is somewhat above the temperature of the filament (1368°K). In the presence of hydrogen, this current-voltage line is shifted towards lower voltages and in the presence of oxygen, towards higher voltages.

Since writing this paper, the article by Davisson and Germer has appeared.[3] Many of the phenomena which they describe agree with those observed by the writer. Their value for the work function is higher than that found by the writer for good vacuum, but this difference may be within the limits of variation of this type of filament or the filament may have been in a condition intermediate between those represented by the two curves of Fig. 1.

In conclusion the writer wishes to express his thanks to Dr. Saul Dushman for his many helpful suggestions and his constant interest and encouragement.

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[3] Davisson and Germer, Phys. Rev. 24, 666 (1924)