I. PHYSICAL ELECTRONICS

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The above staff are working on the development of a coordinated program of research in physical electronics with the present concentration of interest as indicated in the following sections.

A. ELECTRON EMISSION PROBLEMS

1. Thermionic Emission from Sintered Cathode of Thoria and Tungsten Mixture

Staff: Dr. H. Y. Fan
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Sintered thoria cathodes have been found more suitable compared with other types of cathodes for use in high-power magnetrons. On account of the high resistivity of thoria it is necessary to provide such cathodes with a heater. By mixing tungsten powder with thoria the resistivity of the sintered cathode can be adjusted to a suitable value for direct heating. The present report concerns the thermionic emission properties of such a cathode.

The cathode is made of thoria and tungsten powder mixture, 33 per cent W and 67 per cent ThO_2 by weight, pressed into the form of a sleeve, 1 in. long, 0.257 in. outside diameter and 0.192 in. inside diameter. The pressed sleeve is sintered in a hydrogen furnace at 1800°C for one-half hour. Molybdenum cylinders are platinum-brazed to the sleeve to serve as current leads. The cathode has a cold resistance of 0.06 ohm and is directly heated. It is mounted in a glass tube with tantalum anode and guard rings of 1 in. diameter. The lengths of the anode and guard rings are 7/16 in. and 1/2 in., respectively.

The emission properties are investigated in the sealed-off tube. The main results are: 1) For sufficiently high applied potentials the emission current approaches the theoretical line according to Schottky's theory for accelerating fields. The shape of the curve is as expected from the patch theory, in this case patches of tungsten and thoria. 2) Pulsed emission of 10-μsec duration and 180 cycles repetition rate shows no decay. 3) After heating the cathode at 1750°C and bringing the temperature down to a lower value, the emission tested at different time intervals decreases

with time and continues to do so for many hours. If the cathode is heated to 1750°C again, the emission starting from some lower value always increases to a stable and consistent value. 4) The Richardson plot of initial currents immediately after heating at 1750°C gives the values $\varphi = 2.9$ ev for the work function and $A = 4.37$ amp/cm^2/degree^2. D-c and pulsed emissions all fall on the same straight line.

This work is being performed in connection with the high-power magnetron project (Sec. VI).

2. Studies on Oxide-Coated Cathodes. Correlation of Pulsed and D-C Emission and Decay of Pulsed Emission

Staff: Dr. R. P. Bien

This investigation was undertaken with the following working hypothesis: Provided the state of the oxide coating is kept constant within chosen ranges of temperature and accelerating field, there is no ground for supposing that the emission characteristics under pulsed conditions should be different from those under ordinary d-c conditions. Under this assumption the application of square pulsed fields for drawing large emission current is essentially a device to avoid the difficulty of tube limitations in power dissipation.

Preliminary work showed that at 920°K or thereabouts, pulsed emission does not stay constant for pulse lengths of 1 and 3 μsec when the repetition rate is as low as 60 per sec (p.p.s.). With 10-μsec pulses, p.p.s. 60, although each individual current pulse is square, as shown on a synchroscope, the square current pulse amplitude continues to decrease in a matter of seconds. At lower temperatures, which do not seem to have been used for pulsed emission studies, the state of the cathode as evidenced from emission can be held constant. For all tubes tested this state was constant at and below 840°K for pulse lengths 1 and 3 μsec up to p.p.s. 180. At a 840°K, pulse length 10 μsec and p.p.s. 60, pulse current amplitude is constant but begins to show slight decay at p.p.s. 180. Repeated tests, after two or three weeks, and after d-c emission characteristic measurements always yielded the same emission values within 3 per cent which is within the experimental error of the method of measurement used with the synchroscope. At no time, of course, has the temperature been raised beyond 840°K, and 1- and 3-μsec pulses at r.p.s. rates 60 and 180 were always used.

Richardson plots for zero-field currents obtained from extrapolation of Schottky plots for both pulsed and d-c emission do indeed exhibit good continuation of zero-field currents in straight lines, thus demonstrating the validity of the hypothesis made for this test. Three tubes, kindly supplied by the Raytheon Manufacturing Company, were used, all of "pure" nickel core, but two with silicon (one 0.9%, the other 1.78%)

in the oxide coating. All yield good Richardson plots, and the work functions thus determined are respectively 1.16 ev, 1.33 ev (0.9% Si) and 1.44 ev (1.78% Si). The corresponding A values are 10.8 amp/cm^2/degree^2, 21.6 amp/cm^2/degree^2 (0.9% Si), and 45.2 amp/cm^2/degree^2 (1.78% Si).

Further detailed study of pulsed current decay is being made as a function of cathode temperature, pulse duration, and pulse-repetition rate.

3. Work Functions and Conductivity of Oxide-Coated Cathodes

Staff: G. W. Mahlman

For the past three months, considerable data have been obtained relating to the thermionic and photoelectric currents from an oxide cathode, in both retarding and accelerating fields. The coating conductivity has also been measured as a function of temperature by means of a single probe embedded in the coating. It is anticipated that this information will be presented as a technical report to be published in two or three months.

The results will be briefly presented here. The "zero-field" thermionic and photoelectric work functions are found to be 1.5 and 1.8 volts, respectively, both decreasing considerably with increasing applied field. The energy gap between the bottom of the conduction band and the impurity levels, as determined from the variation of coating conductivity with temperature, is found to be 2.4 electron volts for this particular cathode. From this it is concluded that the photoelectric current comes from "surface states" located at energies higher than that of the impurity levels.

Much of the behavior of both the thermionic and photoelectric currents suggests emission from a "patchy" surface. The size of the patches is of the right order of magnitude to be equal to the crystal size, and the patches differ in potential by a few tenths of a volt.

4. Electron Emission under Retarding and Accelerating Fields

Staff: C. S. Hung

The purpose of this experiment is to study the thermionic emission of an oxide-coated cathode in the absence of the disturbing effects of a contaminated anode.

A tube with a sliding-anode feature has been constructed. The collector and the guard rings are mounted on a sliding framework which can be pulled out and shielded from the cathode during the processing of the tube. This design was found successful in keeping the anodes free from contamination by the cathode-coating material. After the completion of the tube, whenever the anodes are suspected to be dirty, they can be pulled out

again and cleaned up by induction heating. However, with the present design, it was found difficult to avoid electrical leakage trouble. Conducting material was found deposited on the supporting glass structure even after the first baking of the tube at a temperature as low as 100°C. The following procedure was adopted to reduce this leakage:

(1) The tube was baked thoroughly at 450°C.
(2) It was cooled down and air admitted to oxidize the conducting deposits.
(3) The oxides were washed off with distilled water.
(4) The tube was baked overnight at 300°C.
(5) And finally, the cathode was submitted to regular processing.

The leakage in this case, was small but still not negligible.

Preliminary measurements, limited by the leakage, were done on two cathodes. Interesting results were obtained in both retarding and acceler ating fields which indicate possibilities of very small patches of the cathode. Further investigation is required.

5. Determination of the Thermionic Emission Properties of Single Tungsten Crystals by a Photometric Method

Staff: C. S. Marcinkowski

The work on phosphor coating methods has been continued with the object of developing a more reliable method of depositing phosphor powder inside glass tubes. The best method found to date works as follows:

A clean glass tube 2 in. in diameter and about 15 in. long is rotated by a motor at 10 rpm about an axis which makes an angle of 10 degrees with the horizontal. While the tube is rotating, a 10 per cent sodium silicate solution is washed inside the glass. This solution is allowed to dry for two minutes and then hot air is blown through the tube until the silicate is tacky. This condition is determined by using a small amount of phosphor in the silicate as a tracer, and drying it until the phosphor starts to set in the silicate. When this happens, in about 3 or 4 minutes, phosphor powder is blown in one end of the tube with a powder blower. A 100-watt lamp below the tube enables one to see through the coating and correct for any irregularities in the thickness of the coating by manipulating the powder blower while the tube is being coated.

A tube has been coated by this method and is being assembled for the first quantitative measurements of thermionic emission.

It is thought that the use of a uniform light-reflecting aluminum coating of optimum thickness on the phosphor may help in reducing errors due to stray scattered light inside the tube. A few unsuccessful experiments

have been made, first to devise a method of uniformly coating the aluminum, and second, to determine the optimum thickness of coating needed.

To perform the electrical tests, P10 Screen Testing Equipment has been set up for the photometric measurements. This equipment consists of a 931A photomultiplier for measuring the phosphor light intensities, associated calibrating equipment, regulated power supplies, and a photoelectric recorder. Some preliminary tests have been made with this equipment to determine the sensitivity and circuit noise of the photomultiplier as well as the over-all behavior of the circuits.

A mechanical scanning device for moving the photomultiplier and tube under test has been built by the machine shop. This unit consists of a 17-in. long vertical drive screw, of good quality, for moving the photomultiplier, and two brass jaws, set in ball bearings, for rotating the tube under test about a vertical axis.

Finally, some studies are currently being made to determine the possibility of improving on the present method of obtaining smooth tungsten filaments.

B. PROPERTIES OF CATHODE-RAY TUBE SCREENS

The work on phosphors has been discontinued for the present. A technical report on the work of W. T. Dyall will be available soon.

C. GAS DISCHARGES

1. Langmuir Probe Measurements in the Mercury Arc Operating in the Transition Range Between Low and High Pressures

Staff: Katherine L. Franck

The object of this experiment is to obtain quantitative data on which to base an extension of probe theory to electrical discharges in gases at pressures of one third to one half an atmosphere. In this investigation, a stationary probe is to be used and the positive column of the arc is to be swept across it by means of a magnetic field.

Two experimental tubes have been constructed. The electrodes at each end of the discharge tube consist of a ten-turn coil of tungsten wire located on the axis of the tube. A small piece of thorium inserted into the coil melts during the first few seconds of operation and thereafter fills the interstices of the coil. The distance between the electrodes is 4.8 cm. The tube contains a known weight of mercury and argon at 10-mm pressure as starting gas. In one of the tubes a 10-mil tungsten wire probe is stretched diametrically across the tube midway between the two electrodes.

At present, studies of the operational characteristics of the tube without the probe are being made to determine the effect of the presence of the magnetic field. The tube is connected in a circuit that allows a control of the current range from 0.5 amp to 3.0 amp d-c, and it is mounted between small Helmholtz coils (5-cm diameter) in an oven.

Preliminary runs seem to indicate that the voltage drop across the tube varies linearly with the temperature, t, over the range 250°C to 350°C (corresponding pressure range is from 75 to 300 mm Hg), and the observed voltage was 40 volts to 90 volts. The slope of the line expressing voltage as a function of temperature is very nearly half a volt per degree, and appears to be independent of the current and the detailed conditions at the cathode. At a constant current, a change in the cathode spot shifts the whole curve parallel to itself. The voltage difference at constant temperature between two such curves may be as much as 6 volts.

Arc-characteristic curves have been made at temperatures near 350°C for relatively constant emission conditions. These indicate that there may be some effect due to the presence of the magnetic field, but at the present time, the uncertainty in the measurements is of the same order of magnitude.

D. EXPERIMENTAL TECHNIQUES

1. Spectral Emissivity of Tungsten

Staff: Professor W. B. Nottingham
W. E. Mutter

A number of difficulties experienced earlier in this work have been eliminated through improvements in the optics of the apparatus, and further measurements have been made in the range of 1100 to 2000°K. It has been established that the spectral emissivity values obtained are higher than the true values because of a background of illumination from light scattered by the walls of the source envelope. In the course of approximately 100 hours of operation of the present source, this background illumination has increased from 1.5 to 9 per cent of the image illumination through progressive evaporation of metals on the walls of the tube. However, sufficient data are available to make a reliable correction for this effect. A second source tube, now nearing completion, will provide a check on the low-temperature range and allow the measurements to be extended to about 3100°K.

A red-sensitive photomultiplier (1P22) specially selected for high signal-to-noise ratio has recently been obtained. With this tube measurements may be made to 800 millimicrons which is about 100 millimicrons beyond

what was possible with the standard blue-sensitive tube (1P21). Figure I-1 shows the variation of the spectral emissivity of tungsten with wavelength at 1700°K and is typical of the data being obtained. The two open-circle points lying above the line represent values obtained by Worthing and Forsythe[1] using the usual pyrometric method. Since practically all experimental errors would be expected to yield high emissivity values, there is some indication here that the design of the present experiment is satisfactory.

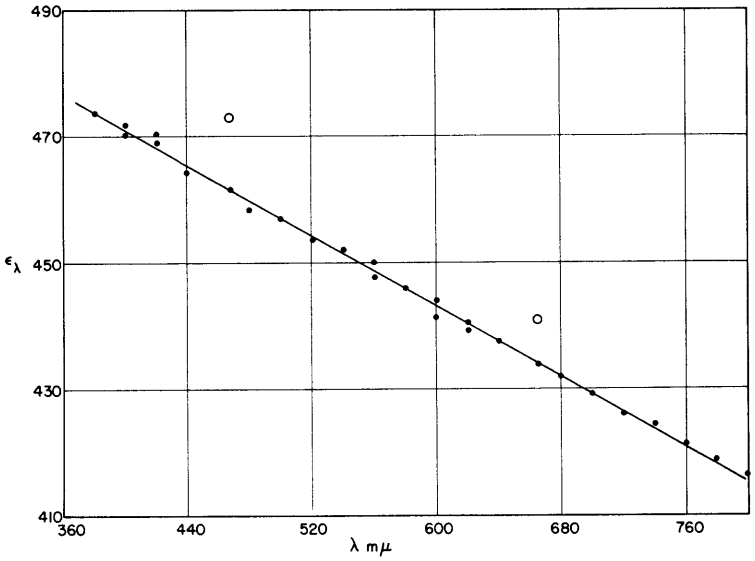

Fig. I-1. Spectral emissivity of tungsten as a function of wavelength at 1700°K.

2. Study of Vacuum Technique as Indicated by a New Type of Ion Gauge

Staff: Professor W. B. Nottingham
L. Sprague

An ion gauge has been designed and constructed that has five elements which may be enumerated as follows:

(a) Hairpin filament used as source of electrons.
(b) Spiral filament for the collection of electrons with axis along center of hairpin filament.
(c) Cylindrical collector of ions having six open "windows".
(d) Ion collector concentric and slightly larger than part (c) cut away so that x-rays and light cannot fall directly on any part of this collector.
(e) Surrounding cylinder, also a collector of ions, connected electrically to part (c).

In the operation of this gauge, over 95 per cent of all the ions are collected on parts (c) and (e), whereas a few per cent of the ions

1. A. G. Worthing and W. E. Forsythe, Astrophysical Journal 61, 146 (1925).

are attached to part (d) by the fact that it is maintained at a negative potential of 45 volts with respect to the hairpin filament. Parts (c) and (e) are at minus 22.5 volts. The combination of parts (a), (b), (c) and (e) constitute an ionization gauge of a design that makes it equivalent in operation and sensitivity to the conventional ionization gauge. Calibrations of the gauge operating in this manner show for argon gas the collection of one ion per million electrons at a pressure of 5×10^{-7} mm, while for nitrogen the same ratio occurs at 8.5×10^{-7} mm pressure. Over the range of pressure from approximately 10^{-6} up to 10^{-2} the calibration is satisfactorily linear as determined by a McLeod gauge. At pressures above 10^{-2} the ion yield is less than the extrapolated value. The ion current observed at electrode (d) is the same for a given electron current with either argon or nitrogen. Over a range of pressure from 2×10^{-4} up to 3×10^{-2} mm, the ion yield is not quite directly proportional to the gas pressure, as indicated on the McLeod gauge, but rises in proportion to the 1.16 power of the gas pressure. It is thought that this increased yield may result from collisions between ions and atoms, as the gas pressure is increased. At lower pressures the ion yield seems to be more accurately proportional to the pressure.

Fifteen cm away from the center of the ion gauge, a coiled filament of about 10 turns is located. After flashing it at a high temperature, this filament is presumably free from surface gas. Under the best of vacuum conditions that we have obtained to date with this tube, gas accummulates on the filament for a period of approximately 150 minutes. This accummulation of gas is indicated by the fact that the ballistic throw of the two ion-current indicators is very accurately directly proportional to the time that the filament is permitted to remain cold up to 150 minutes. As long as the conditions within the vacuum system remain unaltered, no further accumulation of gas takes place on the filament for periods of observation up to 28 hours. During the time that this gas is accumulating on the filament, the ionization gauge indicates a "background" pressure of 8×10^{-9} mm. Since 4-1/2 minutes would be required to adsorb a monolayer of gas on the filament at a pressure of 10^{-8} mm, the indication is that the partial pressure of the gas that is becoming adsorbed on the surface is probably near 3×10^{-10} mm. An interesting point in confirmation of this hypothesis was observed when one of the pumps of the pumping system was turned off. During the off period, the rate of rise in the adsorbed gas was found to be more than double the previous value, whereas the ionization gauge indicated no appreciable increase in background pressure.

It is the object of this research to discover means by which improvements in vacuum may be recognized and vacuum-pumping schedules devised that will result in vacuum conditions hitherto unattainable.