X. Microwave and Physical Electronics

A. Construction of 5 mm. Oxford Type Tube

Staff: Mr. N. G. Parke

A scaled down version of the 2K-33 tube was designed by G. H. Vineyard, January 4, 1946. It differed from the 2K-33 in the following features.

1. Gun not scaled down.
2. Hole through which beam passes scaled down to \( \frac{1}{4} \) not \( \frac{1}{2} \).
3. Outer cavity \( \lambda/4 \) long instead of \( 3\lambda/4 \).
4. Glass in outer cavity placed out in the output waveguide.

Progress to date:

- One tube 80% complete = Tube A
- Two tubes 10% complete = Tubes B and C

Tube A has been used to solve practical assembly and brazing problems. During the final brazing a crack developed in the Kovar outer cavity which is sealed to a glass tube holding the gun. The crack will prevent a perfect seal but the use of glyptol will enable the tube to be tested on the pumps. The plumbing necessary for the test and the power supply are completed and ready.

The future plans are:

To complete Tube A and test for oscillation, to check details of assembly of Tubes B and C to prevent a second cracking of Kovar outer cavity, to plan brazing method so that it can be completed in one H₂ firing except for the subassembly of output waveguide. This will cause some delay in the completion of Tubes B and C.

B. Construction of High Power S-band Magnetron

Staff: Professor S. T. Martin

Design and construction of a very high power S-band magnetron is now in the preliminary stages. The initial design will be based on consideration of those features which will conceivably allow achievement of ten megawatts of peak power at a pulse length in the neighborhood of 0.5 microseconds and an average power of about one kilowatt.

The design will follow closely a scaled version of the AX9 (Columbia Radiation Laboratory), an X-band rising sun magnetron which has achieved a power of one megawatt at the same pulse length at an efficiency of 50%.

Extrapolation of the reduced characteristics of this tube indicate that the scaled tube should be able to achieve a power in the neighborhood of 3 to 5
megawatts before a current density corresponding to failure in the unscaled tube is reached.

Present work is confined to evolving techniques for the manufacture of the three-inch waveguide output window and redesign of the end spaces and cathode mounting, since an end mount cathode will not be feasible. It has been ascertained that a thoria cathode will give the required current and the Bartol Foundation workers have reported that thoria cathodes of the necessary size and shape can be fabricated by them as soon as detailed specifications are available.
I. C. Magnetron Theory Research

Staff: Dr. G. I. Harrison

The problem of the behavior of a magnetron consisting of a plane cathode, plane anode, d. c. voltage between cathode and anode, d. c. magnetic field parallel to the cathode and anode surfaces, and r. f. voltage superposed on the d. c. voltage between cathode and anode is being treated theoretically. The case where the magnetic field is greater than the cutoff value has been considered, so that no d. c. current flows between the electrodes. The problem that has been considered is the r. f. current resulting from the impressed r. f. voltage, and the resulting r. f. impedance or admittance. Since no electrons actually reach the anode, it is clear that the r. f. current is of the nature of displacement current, in the region near the anode.

The interest in this problem is two-fold. In the first place, it forms one of the simplest examples of r. f. magnetron action, and a careful study of its theory, coupled eventually with an experimental study of a comparable case, should be valuable in comparing magnetron theory with experiment, which has been very inadequately done up to the present. Experimental checks could be made on a cylindrical magnetron, which would not be very different from the linear magnetron for which the calculations are being carried out. The second reason for interest is more practical. The magnetron of the type described forms an r. f. load, with resistance and reactance. The impedance depends on the electrical parameters of the circuit, and hence can be varied electrically. Such a device could thus be used as an electrically tuned reactor, and could be attached to a resonant cavity, as a magnetron cavity, so as to tune it electrically. Various types of electronic tuning for magnetrons have already been used, some based on a principle similar to that considered here, and study of the parallel plate magnetron seems like a first step toward understanding the theory of electronic reactors of the magnetron type, which has hardly been touched up to the present.

The calculation has so far been only a first approximation, in which the effect of the space charge on the field acting on the electrons has been neglected, the assumed electric field being independent of position, though varying sinusoidally with time. Under these circumstances the motion of an individual electron can be calculated analytically, so that at first sight the problem of finding the r. f. current would seem to be trivial. The reason why
it is not, is that electrons leaving the cathode in certain phases return to the cathode after one period, while in other phases they may not return for many periods. The problem is then to find how many electrons will still be in the interaction space at any phase, taking account of those which strike the cathode and are presumably lost to the discharge. It is assumed that electrons are emitted from the cathode at a uniform rate. A further refinement, which has not been carried through, would take account of the fact that the rate of emission would really have to vary over a period of the r. f. field, in order to be consistent with an instantaneous space charge limitation.

Subject to the approximations above, the calculation has been carried through, partly numerically and partly analytically, in such a way that the r. f. current as a function of r. f. voltage is known, as a function of frequency, for at least certain r. f. voltages, and ranges of d. c. parameters. There is a resonance at the Larmor frequency, the resistive component rising to a maximum at this frequency, and the reactive component going through zero, the Q of the resonance being small, of the order of magnitude of 10. Furthermore, the discharge is non-linear, the r. f. current being by no means proportional to the r. f. voltage. There is some evidence that there is a linear range for small r. f. voltages, the linear range decreasing as resonance is approached. Work is still under way to investigate the range of linearity of the impedance. The main part of the calculation has been completed and written up. Pending completion of the theory, no experimental check has been started.

I. D. Oxide Cathode Research

Staff: Dr. A. S. Eisenstein
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Mr. W. E. Matter

(1) Electron and X-Ray Diffraction Studies

The thermionic emission properties of oxide cathodes are directly related to certain physical and chemical structures present in the cathode. A study is being made to obtain an accurate description of these structures and if possible to determine their effect on the cathodes thermionic activity. This study involves specific investigations of the following subjects:

1. Complex oxide structures and their relation to (a) pulse and (b) d.c. available emissions, and their variation with temperature and life at fixed emission levels.
2. Nature of the interface (oxide-base metal contact) layer as related to the oxide and base metal composition.

3. Variation of the interface composition and thickness as a function of the processing time and temperature cycle.

4. Effect of various interface types on available d.c. and pulse emission.

5. Crystal lattice imperfections and their relation to thermionic activity.

Discussing now in turn, the work done thus far on each of these problems at Radiation Laboratory and in Basic Research:

1. A cathode coating initially an equal molar solid solution of BaO and SrO will lose BaO by evaporation. Variations in oxide coating composition as a function of depth below the surface have been investigated in cathodes operated without the flow of emission current only. X-ray diffraction techniques are used in this work. These studies of time changes are being extended to cathodes operated under high d.c. levels, i.e., current densities of the order of 1 amp/cm². The oxide appearing on the cathode surface seems to set the field limited sparking characteristics of the cathode, BaO, 100 KV/cm and SrO, 50 KV/cm. This effect is being checked with cathodes of four types (1) pure BaO, (2) pure SrO, (3) BaO layer over SrO and (4) SrO layer over BaO.

2, 3, 4. X-ray diffraction techniques were used at the Radiation Laboratory for the study of interface compounds. A cathode made of a BaO coating on a 5% Si-nickel base metal will develop a BaSiO₃ interface which seems to markedly reduce the pulse emission obtainable from the cathode. Interface compounds were found in cathodes made on pure Ni, Cu, Cr, and nickels containing Si, Cr, and Ti. Electron diffraction techniques are now being used in this investigation. Thin films of Ba or BaO are evaporated onto the clean metal surface and their emission d.c. and pulse properties studied as well as their chemical composition. The evaporation is carried out in the electron diffraction chamber at pressures less than 10⁻⁶ mm. Diffraction patterns are taken of the active surface at varying stages of thermionic activity.

5. Precision back reflection x-ray techniques are being used to
measure accurately the variation of crystal lattice constant with composition. A suspected non-linear variation in the solid solution (BaSr)O would indicate strains which are set up in the lattice. Measurements of diffraction line broadening will be used to check the lattice spacing imperfections introduced by strains.

(2) Probe Studies

Data in the literature suggest that it should be possible to obtain some further information on the properties of oxide cathodes by inserting probe wires in the coating and measuring their potentials under different conditions of pulsed operation of the tube.

A technique has been developed for making diodes with two 0.005" nickel probe wires inserted at different depths in the coating. Measurements on these tubes enable one to determine the coating resistance and the anomalous resistance at the interface between the cathode sleeve and the coating. Coatings of an equal molar solid solution of BaO and SrO have been used in the work to date. Cathode sleeves of both electrolytically pure nickel and nickel with about 4% silicon added have been used in the three tubes made thus far.

It is expected that the Ni + Si sleeves will have a high interface resistance relative to the pure Ni sleeves. It is planned to use sets of such tubes with relatively high and low interface resistances to look for possible effects which interface resistance might have on the thermionic emission properties of oxide cathodes. Pulse life test equipment has been set up for aging these tubes and studying these effects over a period of time.

A method of measuring probe voltages while current is being drawn to the probe is now being worked out. It is believed that such measurements interpreted on the basis of the current-voltage characteristics of the probes might lead to more accurate and consistent results than obtained with the null methods used heretofore.

Attempts will be made to correlate interface resistance data with Dr. Eisenstein's X-ray diffraction studies of the compounds formed at the interface and with the thickness of these compounds.

Attempts will also be made to correlate information on conductivity with that obtained by other workers, and to interpret such information insofar as possible in the light of the modern electron theory of solids. Some thought
is being given to the design of a tube in which current can be passed through the oxide coating in either direction and probe measurements taken. If the high interface resistance observed in work to date is due to a blocking layer at the interface, its value should be much less for the passage of current in the reverse direction.

I. E. The Transmission of the Photo-effect in Silicon

Staff: Dr. F. C. Brown

It has been demonstrated that if one end of a 4.5 cm. silicon crystal is illuminated, there is an accompanying increase of electrical conductivity at the opposite end. This change is the same whether the current flows transversely or longitudinally. The immediate objective of the research is the measurement of the attenuation and the velocity of the effect, and the correlation of these results and later the major objective is the correlation of the results with the other electrical and optical properties in order to obtain a basic understanding of the phenomenon.

The velocity is measured by illuminating the crystal successively at two points through two windows in a disk rotating 30 or 60 times a second. The time at which the effect reaches the electrically conducting part of the crystal is measured on an oscilloscope.

With the disk rotating in one direction, the form of oscilloscope curve is thus \( \frac{X}{t} \), and with the rotation reversed the curve is \( \frac{X}{t} \). The minor pips arise from the effect transmitted at a distance from the electrodes, whereas the major pips arise from illumination at electrodes. The time between the major pips and between the major and minor pips, makes it possible to compute the distance travelled by the effect, the time required, and the velocity. For the distance of transmission of 7 mm., the velocity has been determined to be 400 meters/sec. It is yet to be determined if this velocity varies with distance of travel and with temperature.

The attenuation was obtained by measuring the equilibrium conductivity when the crystal was illuminated at different distances from the electrodes. If \( N \) is the number of electrons activated by the light, then the change of conductivity is a constant \( \times N \). The curve in the accompanying figure shows the variation of the effect with the distance of the illumination from the electrode.
On the theory that the light effect frees electrons which are recaptured at rate $a$ and which travel with velocity $v$, 

$$\frac{dN}{dt} = -aN^2 - ve^{-x} \frac{dN}{dt},$$

we get $\frac{1}{N} = \frac{G(e^{-x} - 1)}{N_0}$.

The straight line is the plot of $\frac{1}{N}$ against $(e^{-x} - 1)$. Thus for the direct measurements of velocity, there seems to be no significant variation with distance of transmission, and there is a decided discrepancy between this and the attenuation experiments. This discrepancy may be due to variation of recapture coefficient with distance.