I MICROWAVE AND PHYSICAL ELECTRONICS

A HIGH-POWER MAGNETRON RESEARCH

Staff Professor S T Martin
J H Henry
R R Moats

Description of Project The exploration of the fundamental engineering problems which prevent production and utilization of higher microwave power than is realized by available tubes is the primary object of this project

Status The 10-Mw S-band tube referred to in the January Progress Report has been assembled to the point of welding the output window the final operation Cathode activation tests have proceeded satisfactorily Parts for two additional tubes will be assembled as soon as the assembly procedure is completely determined

Research on the fabrication of sintered thoria cathodes suitable for use in the above tubes has progressed to the point of installation and test of the necessary furnace Some preliminary work on the molding of thoria with desirable admixtures has been done

Since the last Progress Report was prepared the chrome-iron alloy sheets required for the preparation of mica output windows (for waveguide output) were obtained, and several large size $3\frac{1}{2}$-inch diameter mica windows prepared and tested The mica itself is strongenough to support atmospheric pressure over a circular sheet of the above diameter and 0 015 in thick However the glass which bonds it to the metal cannot stand the stress and usually ruptures A rectangular window 4 in x $1\frac{1}{2}$ in , held with a steel retaining ring bonded with glass at the edge, held the pressure, although there was some cracking of the bonding glass A variant of this design will be investigated to see whether a solution of this purely mechanical problem cannot be obtained

The investigation of π-mode frequency and frequency separation of the n=8 mode in 18-cavity rising sun anodes, with slot shapes as shown in Fig 1 , was undertaken to obtain design data, since this modified type of construction is comparatively easy to accomplish when hobbing is not feasible As a matter of interest the theoretical performance of an infinitely long anode was calculated for comparison The results are shown in Fig 2 Here the calculated and observed π mode and n=8 mode frequencies, and the calculated and observed percentage wavelength separation, $(\lambda_{\pi}-\lambda_{8})100/\lambda_{\pi}$, between the n=8 mode and the π mode are plotted, for a series of anodes in which the dimensions of the small cavity were systematically varied Anode dimensions are shown in Fig 1 in which 2θ is the angle subtended by the small cavities at the center of the tube The length of the small cavities was adjusted to keep the theoretical π mode frequency constant The wavelengths referred to are free space wavelengths Mode identification was accomplished by the usual procedure of observing the azimuthal variation of field strength in the cathode-anode interaction space, with a rotating probe

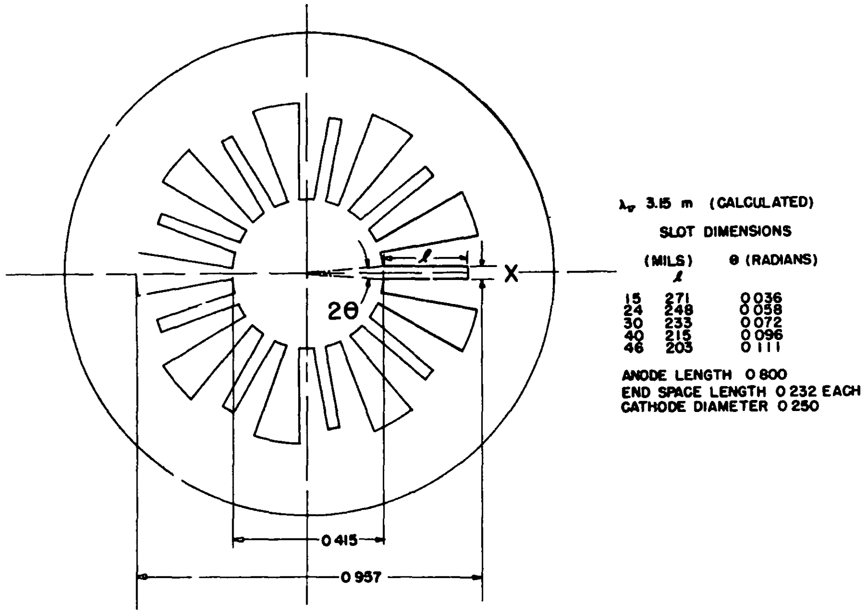

Figure 1 Cross section of 18-cavity rising-sun anode; significant parameters shown

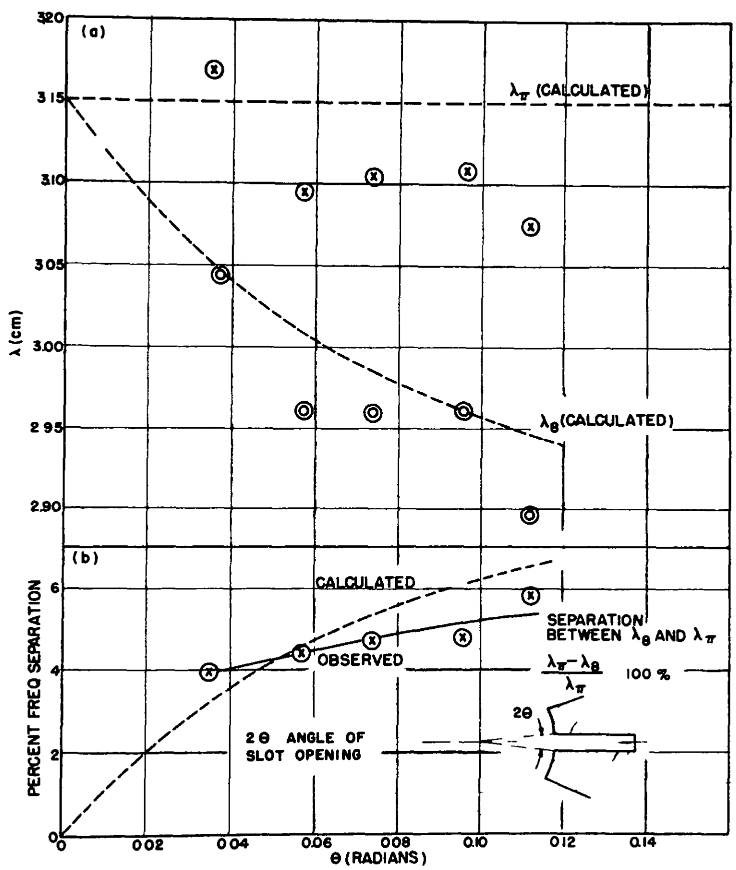

Figure 2 (a) Wavelength of π mode and n=8 mode
(b) Per cent frequency separation between π mode and n=8 mode
Both (a) and (b) are for a series of anodes of the type shown in Fig 1 The plotted points are observed values

I B CATHODE RESEARCH

1 Cathode Interface Studies

Staff A S Eisenstein

Measurements of the electrical conductivity of (BaSr)O, an oxide cathode coating, and Ba_2SiO_4, an oxide cathode interface material, as described in the January Progress Report, have been extended in the tube shown in Fig 1 This design minimizes the temperature ambiguity due to an unknown coating emissivity and transmission In this tube the coating, containing four imbedded probes (2, 3, 5, 7), covers the surface of a MgO ceramic which is mounted at the center of a completely enclosed tantalum "furnace" The furnace is heated by means of an induction coil placed around the tube Pyrometer readings of temperature are made through a small hole in the furnace wall When assumed to represent black body radiation these readings are in close agreement with thermocouple temperature values

The results of this study are shown in Fig 2 The specific conductivity is plotted on a logarithmic scale as a function of the reciprocal temperature ($10^4/T^oK$) for samples of the two materials If it is assumed that the slopes of these curves are equal to E/2k, values of the activation energies E may be obtained Curves 1, 2, and 3 were taken on successive days on a single sample of (BaSr)O Curves 4, 5, 6, and 7 represent different states of activation of a sample of the Ba_2SiO_4 interface material

These results together with the earlier observation that the interface thickness may be 1/10 that of the total coating thickness suggests a possible energy level configuration of the complete cathode Figure 3 shows this model for the case of zero emission (I=0) and for the case of high pulsed emissions (I>0) The high potential barrier at the interface results from joining the Fermi level of the base metal with the effective W_1 level of the interface and coating, this level approximately splitting the forbidden band (E) between the impurity levels and the bottom of the conduction band When an anode voltage V_A is applied, the flow of electrons causes a tipping of the energy levels to an extent which depends upon the conductivity of the material This tipping depresses the W_1 level of the coating near its surface below the Fermi level of the metal by an amount V_{ic}, the voltage drop across the interface and coating Since it is the voltage drop (V_A-V_{ic}) between the oxide surface W_1 and the anode which is involved in the Langmuir-Child space-charge relation, a 2/3 power plot of the observed current-voltage (V_A) characteristics of a diode should contain the V_{ic} in the form of progressive deviations from the calculated space-charge line This effect may be seen in Fig 4 which shows the observed emission characteristics of a diode having a relatively high interface and coating voltage drop In the temperature range 1040°K to 1300°K values of V_{ic} taken from these emission characteristics are in good agreement with the previously obtained values of the interface thickness and the Ba_2SiO_4 conductivity An increase of V_{ic} is observed with increasing cathode life, this is consistent with a qualitatively observed increase in interface thickness Thus it seems reasonable to suspect that above 1040°K all points on these curves represent space-charge limited conditions at the oxide surface while the 940°K characteristic depicts an emission-limited condition It is hoped that an experiment now in progress

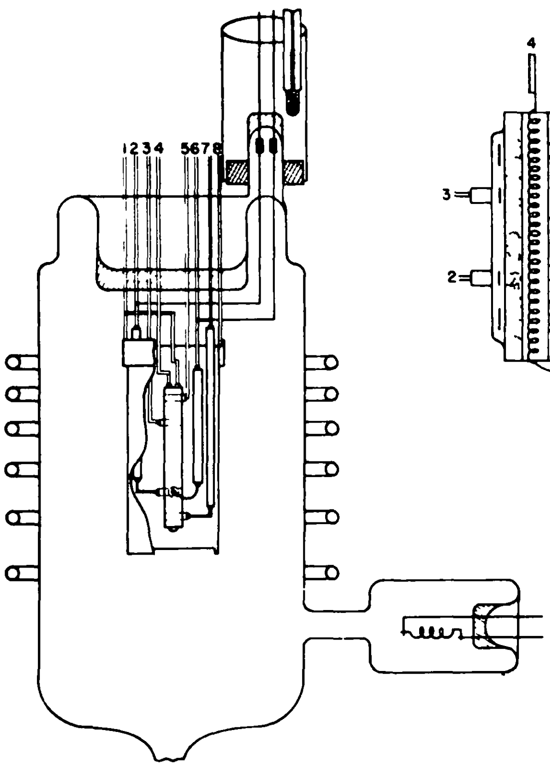

Figure 1 Conductivity tube

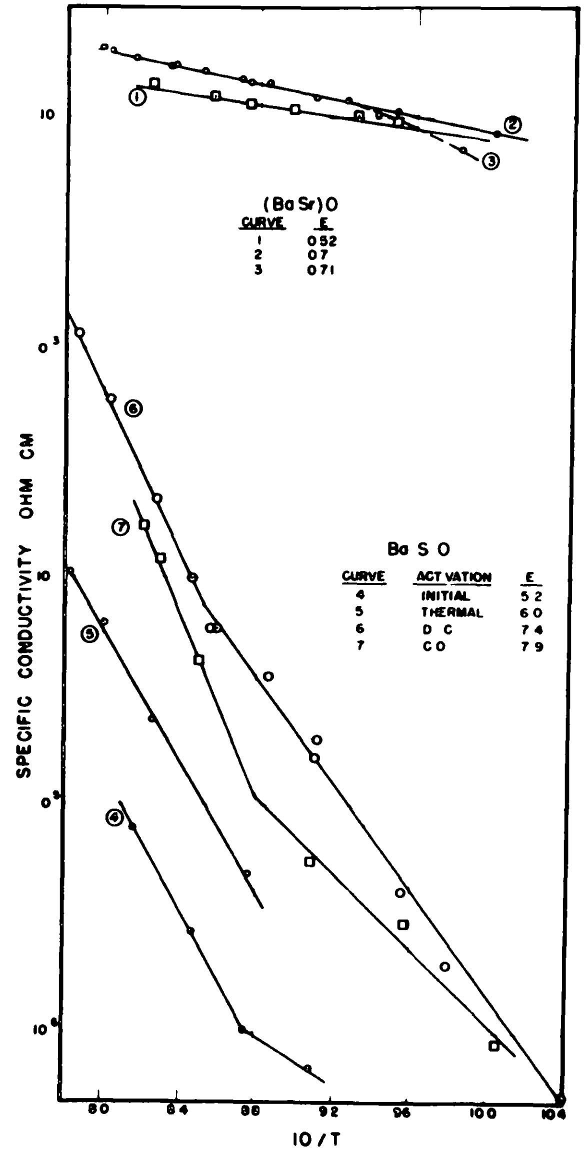

Figure 2 Specific conductivity plotted on a logarithmic scale vs reciprocal temperature

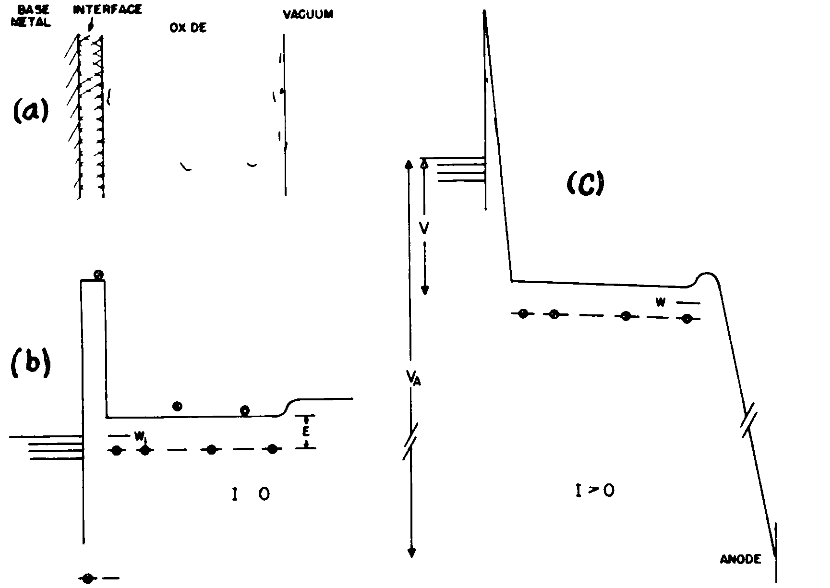

Figure 3 (a) Cross section of oxide cathode
(b) Energy level configuration for no current flow
(c) Energy level configuration with emission current

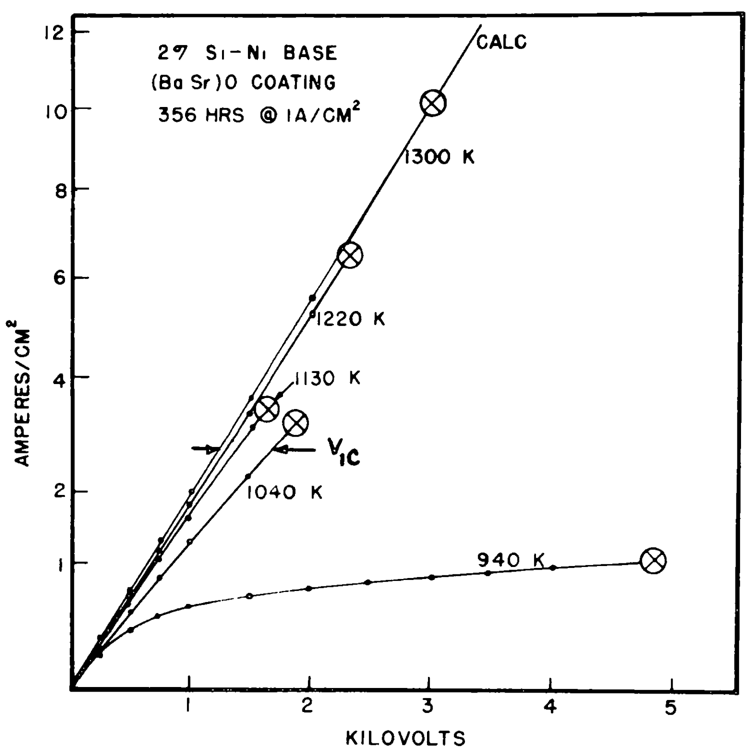

Figure 4 Characteristics of Si-Ni base cathode

will permit a direct evaluation of the potential of the vacuum-oxide surface with respect to the anode

On the basis of the above observations it seemed reasonable to expect that the typical electrical characteristics of a natural Ba_2SiO_4 interface could be duplicated by applying a synthetic Ba_2SiO_4 interface to a pure Ni base metal and coating this interface with (BaSr)O, (see Fig 5) The emission characteristics of this cathode

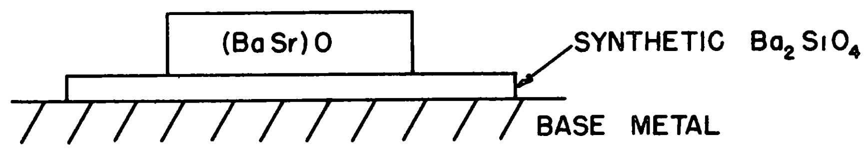

Figure 5 Cross section of synthetic Ba_2SiO_4 interface cathode

are seen (Fig 6) to resemble those of cathodes prepared on a Si-Ni alloy base rather than those on a pure Ni base as regards progressive deviations from the calculated space charge line and the current density at which sparking occurs On the assumption that sparking is due to the I^2R dissipation of the interface reaching a limiting value, a curve is drawn of IV_{ic} = constant The constant is selected to give the best agreement with the observed sparking points Again this assumes space-charge limited conditions at the oxide surface, hence it seems fortuitous that agreement is found with the 940°K sparking point

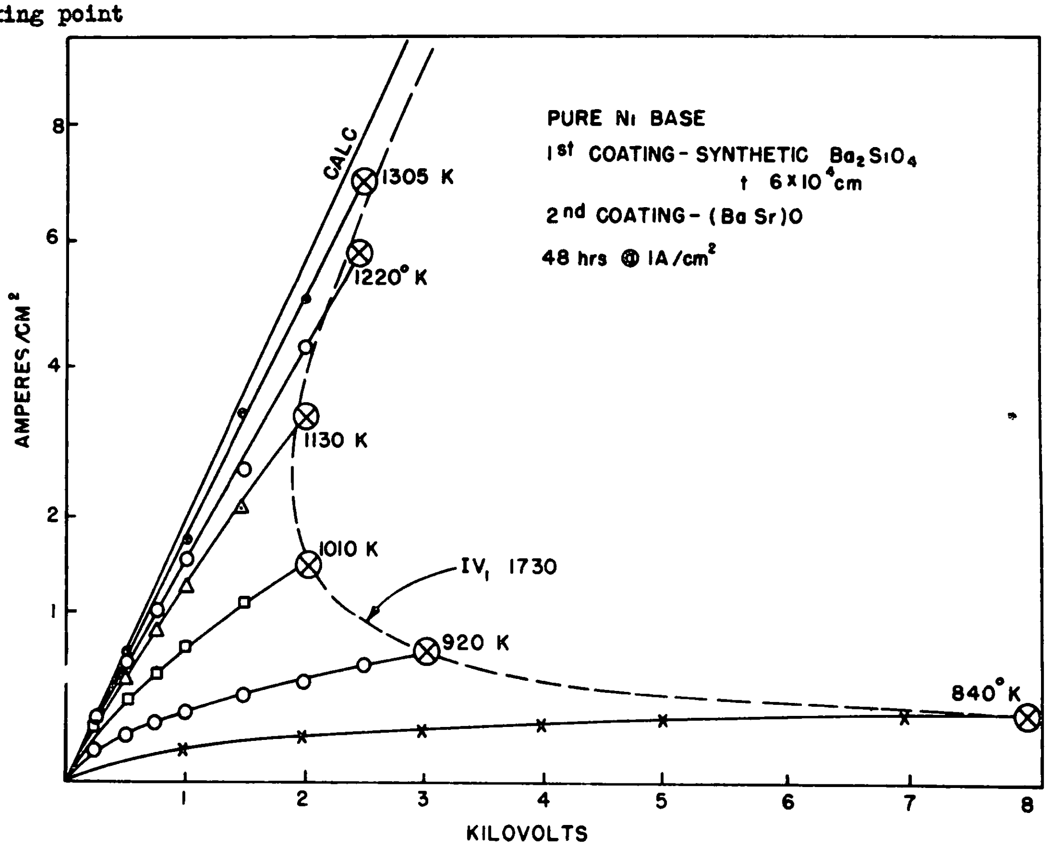

Figure 6 Emission characteristics of synthetic interface cathode

I B 2 The Interface as a Blocking Layer

Staff W E Mutter

Further experiments have been carried out to study the potential drop at the base metal-coating interface when microsecond pulse currents flow in the normal and reverse directions Previously reported results (January Progress Report) on pure nickel base cathodes have been confirmed and extended by the use of a different geometrical structure A rectification action has been observed at the interface formed on 5 per cent silicon nickel base cathodes Probe measurements have been used to explain deviations of the current-voltage characteristics of the experimental tubes from the 3/2 power law

Figure 1 shows the cathode structure of the tubes now being used The two

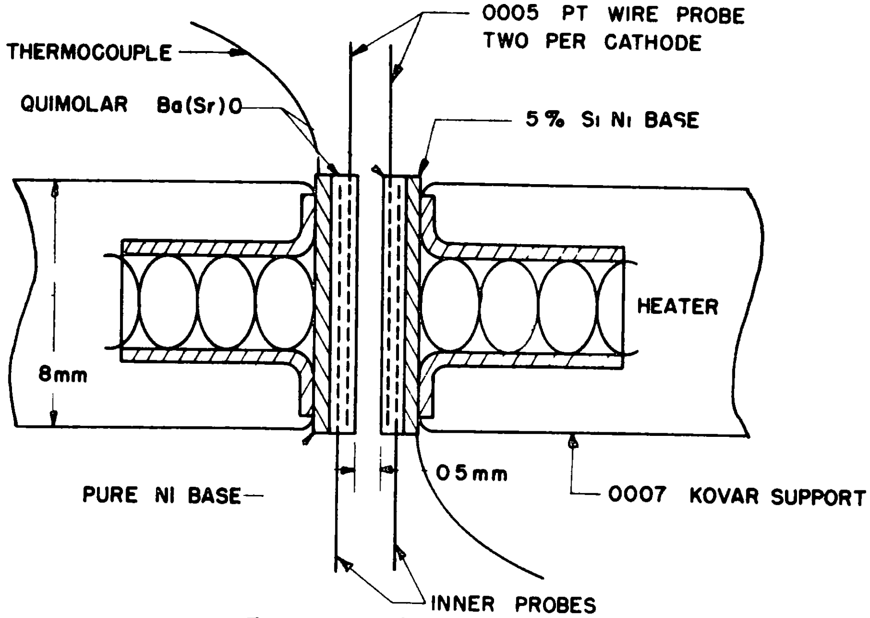

Figure 1 Cathode structure

flat circular cathodes are identical except for the base metal which is a pure electrolytic nickel in one case and a 5 per cent silicon nickel in the other This choice is made to permit a comparison of the potential drops over the interface and coating of a pure Ni and Si-Ni cathode when both are contained in the same envelope and receive the same processing and subsequent treatment Figure 2 shows results obtained at 800°C at the beginning of life The coating conductivity is seen to be independent of current density, direction of current flow and the base metal on which the coating is supported The potential drop over the interface on the pure nickel cathode is small and shows no change with the direction of current flow In the case of the Si-Ni base cathode, the potential drop at the interface rises rapidly in the forward direction to 4 or 5 times the coating drop, while in the reverse direction, it is much smaller (about 1 5 times the coating drop) The forward curve is imaged in the third quadrant for direct comparison with the reverse curve The direction of easy flow indicated here, i e electrons passing from the coating to the base metal, corresponds to that given by Mott[1]

1 N F Mott Proc Roy Soc A171, 127 (1939)

in his copper oxide rectifier theory

It may be seen from Fig 2 that some small potential drop does occur at the pure nickel interface Whether this is the result of small amounts of impurity in our pure nickel or other causes is unknown If it does arise from impurities one might expect the rate of buildup of the interface compound to be controlled by the availability of the reactants and their rate of diffusion to the surface Figure 3 shows the interface potential drop on a pure nickel cathode at various periods of life It increases with time and shows rectification properties in the latter periods, however, the magnitude is still considerably smaller than that characteristic of the silicon-nickel base

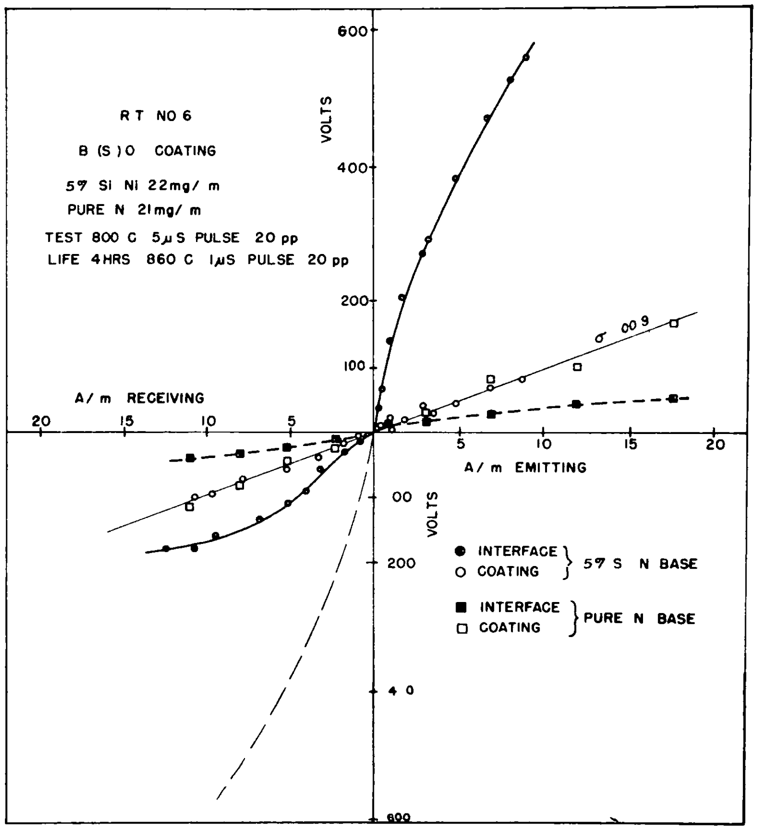

Figure 2 Interface and coating potentials drops on pure Ni and Si-Ni cathodes

Figure 4 shows a Langmuir-Child plot for the structure shown in Fig 1 The lowest curve shows current density plotted against applied voltage This curve has a continuous curvature For the upper curve marked "corrected" the applied voltage at each current density has been reduced by an amount equal to the total coating and interface drops across the two cathodes as obtained from probe measurements These points fall on a good straight line and indicate that the space-charge law is followed when the applied voltage is taken as that existing between the coating-vacuum surfaces of the two cathodes The line without points is calculated from the tube geometry and a measurement of the separation of the two coating-vacuum surfaces The deviation from the corrected line represents a difference of 0 004 in in the spacing measurement This is within the expected error Circuitwise, the system behaves like an ideal diode in series with a relatively low ohmic resistance (coating) and a second larger non-ohmic resistance (interface)

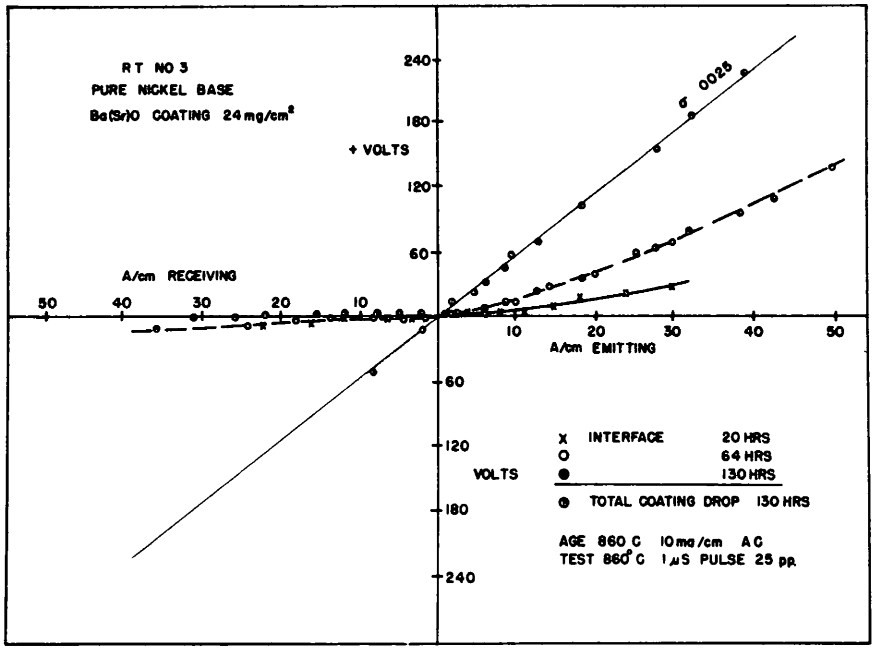

Figure 3 Interface potential drop on a pure Ni cathode during life

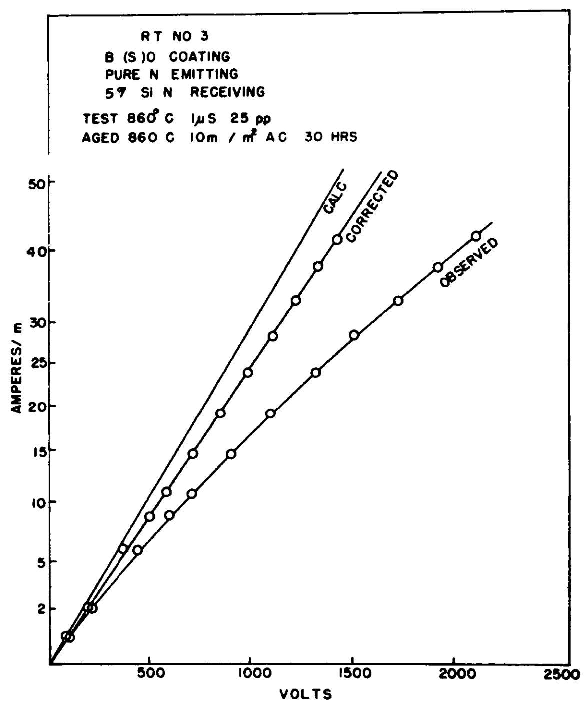

Figure 4 Emmission characteristics for cathode structure of Fig 1

I B 3 Work Functions and Conductivity of Oxide Cathodes

Staff G W Mahlman

An experiment is planned which attempts to measure the photoelectric and thermionic work functions and the electrical conductivity of a single oxide-coated cathode This involves measuring small photoelectric currents by means of an electrometer tube at the lower temperatures, and by means of an a-c amplifier at the higher temperatures where the monochromator's illumination must be modulated in order to separate photoelectric from thermionic currents An attempt will be made to measure conductivity by two probes embedded in the cathode coating This presumably would avoid errors due to interface voltages at present ascribed to compounds which form between the base metal and oxide coating of the cathode The first experimental tube is now under construction

4 Spectral Emissivity of Tungsten

Staff Professor W B Nottingham
W E Mutter

The work on the measurement of the spectral emissivity of tungsten is now in the preparatory state in that the auxiliary electronic equipment to be used for the radiation intensity measurement is being designed and constructed

5 Electron Emission in Accelerating and Retarding Fields

Staff Professor W B Nottingham
C S Hung

Although no new measurements have been made during the past quarter, a new tube has been designed and its construction is well under way

C IONIZATION GAUGE RESEARCH

Staff Professor W B Nottingham
L Sprague

A new gauge design has been made and the gauge constructed The new gauge has not yet been tested and therefore there are no significant results to report

D PROPERTIES OF CATHODE-RAY TUBE SCREENS

Staff Professor W B Nottingham
W T Dyall

The specialized equipment developed during the war for the measurement and evaluation of cathode-ray tube screens is now being constructed and put into an operating condition A program of research is planned and an effort will be made to coordinate the use of the cathode-ray tube measuring equipment with the interests of various Radio Manufacturers Association committees that might like to have special screens investigated for standardization purposes

E DETERMINATION OF EMISSION PROPERTIES OF SINGLE CRYSTALS

Staff Professor W B Nottingham
C J Marcinkowski
M K Wilkinson

Observations have been made that determine qualitatively the relative emission properties of single crystals under both thermionic emission conditions and field emission conditions by observing the relative intensity of light excited on a fluorescent screen under electron bombardment It is the present intention to investigate the feasibility of making accurate quantitative measurements of emission properites by determining the light output as a function of position and operating conditions If the technique can be worked out satisfactorily, it will be applied to both thermionic and field emission studies

I F CONSTRUCTION OF 5-MM OXFORD TYPE TUBE

Staff N G Parke

Description of Project In connection with the investigation of electromagnetic phenomena in the frequency region above 30,000 Mc, attempts are being made to construct a 60,000-Mc reflex velocity-modulated tube

Status As mentioned in previous progress reports, problems of brazing with BT solder and problems of glass-to-kovar seals in the immediate neighborhood of brazed joints demand the development of special techniques, and in many cases, redesign not only of the affected part but also of related parts Most of these problems have been at least partially solved Nevertheless, it was decided to circumnavigate some of these difficulties temporarily with the aid of methods of sealing which require lower temperatures in order to concentrate on the electrical rather than the mechanical aspects of the tube This experimental version of the tube has been constructed, and is on the vacuum system in the process of being tested

Several features of the experimental tube are of interest Preliminary calculations based on values of Q and R_{sh} scaled down from data on the QK-33 indicate a starting current of 4 ma with a beam coupling coefficient of $\frac{1}{2}$, a 2000-volt anode potential, in the 4 3/4 mode The electron gun being used is the same as the one used on the QK-33 Experience shows that, due to the small size of the hole through the reentrant part of the cavity through which the beam must travel (14 5 mils), the assembly tolerances are too close to insure proper gun alignment, that is only 0 1 to 0 5 of the beam current gets through To insure proper gun alignment, the experimental tube is provided with a ground glass joint which in the sealed-off version will be replaced by bellows The ground glass joint is quite successful, the tube can be pumped down to 10^{-6} mm Hg By collecting the beam current on the reflector and observing the reading of a milliameter in series, gun alignment becomes an easy operation resulting in over 0 9 of the beam getting through

In order to insure minimum starting current, the copper disc forming the upper part of the cavity was redesigned to reduce the depth of the output quarterwave choke section to about 3 mils In addition an essentially tubular reflector is being used to give a wide choice of modes with a reasonable variation of reflector voltage By working in a high mode, 6 3/4 or more the beam will have optimum opportunities to bunch

In order to avoid difficulties of r-f plumbing at 5 mm, initial tests will be made by observing the mode shape as reflected in the cathode current Rough wavelength measurements will be made by observing the effect of reflection from the face of a micrometer as it is advanced a half wavelength in air It might be remarked that the development of a tube at this frequency is complicated by the lack of another tube of like frequency which may be used as a bench oscillator When the first tube oscillates successfully, it may be used as a bench oscillator for those which follow and the cruder techniques may be replaced by more refined ones In particular, the method of cold testing will then be available

I G TRAVELLING-WAVE AMPLIFIER TUBES

1 Theoretical Considerations

Staff Dr L J Chu
J D Jackson

As reported in the last Progress Report, theoretical work on a small signal analysis of a helix-type travelling-wave amplifier tube was initiated Briefly, the procedure of analysis is as follows: An infinitely long spiral helix with a cylindrical space-charge region on its axis is treated as an idealized boundary-value problem in which the helix is replaced by a perfectly conducting cylinder with current flow restricted to a fixed angle with the axis of the cylinder The electron beam behavior is idealized to allow only longitudinal motion of electrons and to include only linear terms in charge-current relations In effect, the device is assumed to have a linear behavior throughout so that superposition relations hold Under these restrictions the boundary-value problem is solved by matching the solutions of Maxwell's equations at the interfaces of the three regions inside the beam between the beam and the helix wall, and outside the helix The solution then yields a very complex transcendental equation for the propagation constant in terms of the physical properties of the helix and beam, and the average electronic velocity and current

For a sufficiently small (compared to the helix diameter) electron beam, the transcendental equation can be approximated by a cubic equation which yields three values for the propagation constant It is found that the three waves corresponding to these three values of the propagation constant behave essentially as ordinary waves in a guide unless the average velocity of the electrons in the beam lies within a narrow range approximating the phase velocity of a wave in the helix guide with no electrons present When the electron velocity lies in this range the three waves behave as follows One is attenuated, one is unattenuated, and one is amplified as it travels along the helix The amplified wave, which predominates over the other two at distances remote from the input derives its energy from the electrons which lose kinetic energy in the process

Since the last report, the other limiting case of an electron beam completely filling the helix has been investigated in a semi-quantitative manner The results obtained conform to essentially the same pattern as indicated above Of course the resulting amplification is much greater, because the electrons are being exposed to the stronger fields near the helix wall

The problem of a hollow cylindrical current sheet has also been considered to some extent with results that yield essentially no new information or behavior different from that already obtained

Considerable time has been spent on examination of the approximations, both mathematical and physical, involved in the analysis so that the mathematics is on a firm analytic basis and the physical limitations of the problem are clearly understood It is hoped that in the near future a complete report of the theoretical analysis will be published as an RLE Technical Report

Finally in the last report it was mentioned that our results differed somewhat from those obtained by J R Pierce[1] in his analysis of this type of device Since that time a further communication from Mr Pierce indicates that when the effect of the cutoff modes are taken into account in his analysis our results agree, qualitatively at least, more closely with his

I G 2 <u>Experimental Studies</u>

Staff Professor J B Wiesner
L A Harris

<u>Description of Project</u> The purpose of this project is to build some X-band travelling-wave tubes and to investigate their characteristics The tube consists of a wire helix ten inches long and 1/8 in in diameter, and an electron gun to project a beam of electrons along the axis of the helix The helical line must be matched at each end to X-band waveguide over a broad band

<u>Status</u> The matching characteristics of dummy helical lines have been investigated Short straight antennas on the ends of the line project into the guides parallel to the electric field It was found necessary to provide chokes around the holes in the guides through which the tube projects in order to prevent the loss of r-f power As considerable leakage occurred when the antennas projected completely through the guides, the input antenna was cut slightly short and a quarter-wave choke was provided at the output end

Various thicknesses of antenna were tried but the broadest band was obtained when the antennas consisted of the same wire used in the helix A voltage standing-wave ratio less than two was obtained over a bandwidth of about 800 Mc/sec The insertion loss of the system with a nichrome line was 17 db

Two experimental tubes have been designed to operate with a 1500-volt electron beam One uses a point-focussing gun and the other a gun which provides a parallel beam The latter tube has been completed and is almost ready for testing Parts for the former tube are complete and will be assembled shortly Means have been provided for measuring both the beam current passing through the helix and that lost to it

Auxiliary test equipment and focussing coils have also been completed

---

1 Proc I R E , <u>35</u>,111 (February 1947)