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TOPICAL REPORT

EMITTER TEMPERATURE DEPENDENCE
OF LOWER MODE CURRENT

B. Gunther

July 1970

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I. INTRODUCTION

Analysis and evaluation of converter life test experiments require knowledge of the emitter temperature. However, it is not generally possible to measure the emitter temperature for experiments conducted in a reactor environment. Measurement of the apparent saturation current in the extinguished mode has been suggested^{1, 2} as a means of determining the emitter temperature. This technique appears to be applicable, since theoretical arguments^{1,2,3} show that the apparent saturation current under electron rich conditions is only a function of emitter temperature, interelectrode spacing and cesium pressure, and is independent of electrode work functions.

The purposes of this work are to evaluate this technique experimentally and to compare the results with the suggested theoretical expressions. The dependence of the apparent saturation current on emitter temperature, cesium pressure, interelectrode spacing, and electrode work functions is established using three different pairs of electrodes.

II. TEST CONVERTER

The schematic diagram of the parametric converter is shown in Figures 1 and 2. The electrode surface areas are 2 cm^2 for the collector and 3 cm^2 for the emitter. The guard ring extends approximately 60 mils beyond the edges of the projected emitter area and can be maintained at the same temperature and electrical potential as the guard. Flexible bellows allow changing the spacing from zero to 100 mils. Spacing is adjusted and measured by three micrometer screws

fastened to the emitter and guard support structures. Emitter temperature is determined by optical pyrometry on a hohlraum on the back surface of the emitter.

III. EXPERIMENTAL PROCEDURE

I-V curves were traced with an x-y plotter. Converter load was a dc supply, manually adjusted to trace the curves from low current to ignition and back to near open circuit. A programmable dc supply was used to maintain guard voltage equal to collector voltage.

Data were taken over an emitter temperature range of 1600°K to 1850°K in 50° increments and at spacings of $2\frac{1}{2}$, 5, 10 and 20 mils. Cesium reservoir temperatures ranged from 530 - 660°K. Figure 3 shows a typical set of data at an emitter temperature of 1650°K and a reservoir temperature of 604°K. Ignition occurs between -0.12 and -0.18 V. The apparent saturation region is not always well defined.

Figure 4 shows another set of curves at the same emitter temperature but at a higher reservoir temperature (656°K). The 20 mil spacing curve in this figure differs from the others in that there is a large current increase just prior to ignition. This current rise is barely noticeable in the other curves.

Figure 5 depicts the effect of emitter temperature on the I-V characteristics at a spacing of 10 mils. The five curves correspond to different emitter temperatures, with the other variables held constant. Only at the lowest emitter temperatures is there a somewhat defined "apparent saturation" region. At progressively higher emitter temperatures this region disappears.

A spacing family under approximately neutral conditions is shown in Figure 6 for reference. Under these conditions, current density at ignition is much less dependent on spacing.

The current density at ignition is usually lower than the apparent saturation since ignition occurs before an apparent saturation level is reached. In some cases, ignition current and apparent saturation are essentially equal, as in the lowest temperature curve in Figure 5. Occasionally, at low emitter temperature and large spacing, the ignition current is up to 50% larger than the apparent saturation, as in the 20 mil curve of Figure 4.

The currents used to correlate the data and referred to as ignition current are usually those at the actual ignition point. At high emitter temperatures, the ignition current is defined by the sharp increase in slope of the I-V curve. At the lowest temperatures, where the curves show a pre-ignition rise, the ignition current used for correlation was obtained by extending the apparent saturation region of the curve to the ignition voltage.

A. CESIUM PRESSURE DEPENDENCE

Figure 7 shows the variation of ignition current with reservoir temperature at the emitter temperature of 1750°K for four interelectrode spacings. Observe the presence of a maximum in the output current as cesium reservoir temperature is varied. At low cesium reservoir temperature, the emitted ions are in excess of emitted electrons, and the electron current is emission limited. Hence, as the cesium temperature increases, the output current increases. At high reservoir temperatures, however, there is a shortage of ions and the current is space charge limited. An increase in cesium temperature results in further reduction in ion emission

and, therefore, in lower output currents. Note also that the electron current is a strong function of spacing in this region. Data for other emitter temperatures are shown in Figures 8 and 9.

B. SPACING DEPENDENCE

Inverse ignition current at the reservoir temperature of 620°K is plotted versus spacing in Figure 10. As expected theoretically,^{1,2} a linear relation is observed.

C. COLLECTOR TEMPERATURE DEPENDENCE

The dependence of ignition current on collector temperature was measured by varying collector temperature at constant emitter and reservoir temperature.

The results for spacings of 10 and 20 mils are shown in Figure 11 as ignition current versus collector temperature. At these conditions collector temperature does not affect ignition current.

D. COLLECTOR-GUARD BALANCE DEPENDENCE

All data were taken with the collector surrounded by a guard collector, maintained at the same temperature and potential as the collector. To observe the effect of guard potential on the I-V characteristics, curves were traced of collector current versus collector-emitter voltage and guard current versus guard-emitter voltage. Guard to collector potential for these curves was varied from positive through zero to negative.

The collector I-V curves were not affected by guard potential if the guard was negative to the collector. Likewise, the guard-to-emitter I-V curves did not change with the collector negative to the guard.

Ignition of one of the "diodes" would always cause the other to ignite. Thus, a positive guard would cause the collector I-V curve to ignite sooner

at a lower current, the voltage at ignition displaced by the voltage between collector and the more positive guard.

E. OTHER DEPENDENCIES

The experimental data at the cesium temperature of 620°K are summarized in Figure 12 in terms of ignition current versus emitter temperature at several values of interelectrode spacings. The experimental data are internally consistent within 15°K in emitter temperature. Except for the lowest spacing, the ignition current is linear with emitter temperature; this is in contrast with the expressions that show an exponential relation.^{1,2,3} The discrepancy is probably caused by the fact that the theory describes the behavior of apparent saturation current (lower mode). At high temperatures, the unignited current does not reach saturation, but increases as the voltage is reduced until the point of ignition (Figures 3 through 5). The ignition current is used for emitter temperature determination.

In order to study the effect of emitter work function on the ignition current, data were obtained from a second converter with a (100) tungsten emitter which has a much lower bare work function than the previous (110) tungsten emitter. The data from these converters are compared in Figure 13 for the same cesium reservoir and emitter temperatures. The open and solid circles represent data from the (110) and the (100) tungsten, respectively. It is interesting to note that the two sets of data are in agreement within 25°K in emitter temperature. This observation is consistent with the theoretical predictions.

In Figure 14, additional spacing values are plotted to show the error that can be caused if the interelectrode spacing is not known accurately. An uncertainty of 2 mils at the spacing of 10 mils results in an error of

50°K in emitter temperature. The accuracy of emitter temperature determination by ignition current measurements appears to be limited by the uncertainties in spacing.

A useful working correlation can be obtained by plotting ignition current versus emitter temperature for several values of cesium reservoir temperatures. Such a plot for the interelectrode spacing of 10 mils is shown in Figure 15. Similar plots for other spacings can be constructed from the previous figures. The measured values of ignition current for various cesium temperatures can be compared with this graph to yield the emitter temperature. Note again the linear relationship between the ignition current and emitter temperature. The theoretically predicted exponential relation is compared with the experimentally observed linear dependence in Figure 16. A discrepancy of 50°K in emitter temperature is observed.

IV. SUMMARY AND CONCLUSIONS

As suggested by Wilkins, ignition current measurement is a useful technique for determination of emitter temperature. Data obtained from two converters with substantially different emitters ((110) and (100) tungsten) were in good agreement, showing that the emitter work function does not influence the deduced emitter temperature (within 25°K). Ignition current was essentially independent of collector temperature and, therefore, of collector work function, and was an inverse function of interelectrode spacings. The above results confirm the theoretical predictions.^{1, 2}

It was found, however, that the ignition current is a linear function of emitter temperature. This is in contrast with the theoretical analysis, which predicts an exponential relation with inverse temperature. This difference corresponds to an error of 50°K in emitter temperature determinations.

Ignition current was found to be a sensitive function of interelectrode spacing. A 2 mil error at the spacing of 10 mils can result in an error of 50°K in emitter temperature. If the spacing is known accurately, the emitter temperature can be determined within 25°K using the experimental correlation.

V. REFERENCES

1. D. R. Wilkins and E. P. Gyftopoulos, Report on 26th Ann. Phys. Elec. Conf., MIT, 1966.
2. D. R. Wilkins, Private Communications.
3. C. Warner and L. K. Hansen, Report on 23rd Ann. Phys. Elec. Conf., MIT, 1964.

Figure 1. Schematic Diagram of a Research Thermionic Converter.

Figure 2. Research Variable Parameter Converter.

Figure 3. Typical I-V Curves for Ignition Current Determination.

Figure 4. I-V Curves at Low Emitter Temperature and High Reservoir Temperature Showing Pre-Ignition Rise at Large Spacings.

Figure 5. Effect of Emitter Temperature on Lower Mode Current.

Figure 6. I-V Characteristics at Near Neutral Conditions.

Figure 7. Dependence of Ignition Current on Reservoir Temperature and Spacing at 1750°K.

Figure 8. Dependence of Ignition Current on Reservoir Temperature and Spacing at 1650°K.

Figure 9. Dependence of Ignition Current on Reservoir Temperature and Spacing at 1850°K.

Figure 10. Spacing Dependence of Ignition Current.

Figure 11. Non-dependence of Ignition Current on Collector Temperature.

Figure 12. Summary of 110 w Ignition Current Data at 620°K Reservoir Temperature.

Figure 13. Ignition Currents of Three Different Electrode Pairs at $T_R = 620^\circ\text{K}$.

Figure 14. Effect of Spacing on Emitter Temperature Correlation with Ignition Current.

Figure 15. Suggested Working Correlation of Emitter Temperature with Ignition Current at 10 mils.

Figure 16. Comparison of the Present Correlation with the Semi-empirical Correlation of Reference 2.