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I. SURFACE STUDIES

A. SURFACE THEORY

Theoretical calculations were made of the electron reflectivity for quantum mechanical models of the surface dipole layer. Initially, a study was made on a rectangular energy barrier, as shown in Figure 1-A. The Schrodinger equation is readily solvable for such a potential energy distribution, and the resulting reflectivity, R , can be stated in analytical form:

$$R = (R_1^2 + R_2^2)/(R_3^2 + R_4^2) \quad , \quad \text{for } W < E < W + W_b \quad (1)$$

$$\text{where } R_1 = \left[\sqrt{E(E-W)} + (W+W_b-E) \right] \tanh \left[\frac{\sqrt{2m(W+W_b-E)} b}{\hbar} \right] \quad (2)$$

$$R_2 = \sqrt{W+W_b-E} \left[\sqrt{E-W} - \sqrt{E} \right] \quad (3)$$

$$R_3 = \left[\sqrt{E(E-W)} - (W+W_b-E) \right] \tanh \left[\frac{\sqrt{2m(W+W_b-E)} b}{\hbar} \right] \quad (4)$$

$$R_4 = \sqrt{W+W_b-E} \left[\sqrt{E-W} + \sqrt{E} \right] \quad (5)$$

$$R = (S_1^2 + S_2^2)/(S_3^2 + S_4^2) \quad , \quad \text{for } W+W_b < E \quad (6)$$

$$\text{and } S_1 = \left[\sqrt{E(E-W)} - (E-W-W_b) \right] \tanh \left[\frac{\sqrt{2m(E-W-W_b)} b}{\hbar} \right] \quad (7)$$

$$S_2 = \sqrt{E-W-W_b} \left[\sqrt{E} - \sqrt{E-W} \right] \quad (8)$$

Figure 1-A. Rectangular Energy Barrier Model of a Surface Dipole Layer

Figure 1-B. Triangular Energy Barrier Model of a Surface Dipole Layer

$$S_3 = \left[\sqrt{E(E-W)} + (E-W-W_b) \right] \tan \left[\frac{\sqrt{2m(E-W-W_b)} b}{\hbar} \right] \quad (9)$$

$$S_4 = \sqrt{E-W-W_b} \left[\sqrt{E-W} + \sqrt{E} \right] \quad (10)$$

Electron energy, E , is measured relative to the Fermi level (see Figure 1). W and W_b are the work function and the height of the surface barrier, respectively. Barrier width is b , m is the electron mass and $\hbar$ is Planck's constant divided by 2π .

Reflectivity spectra for this model were calculated on a computer. Typical families are shown in Figure 2. The reflectivity maxima and minima are analogous to similar phenomena exhibited by thin films interfering with light. Such spectral structure of electron reflectivity has been experimentally observed.¹

While the rectangular barrier model may be applied to multi-layered surface structures, the triangular barrier model, shown in Figure 1-B, may be better suited to a dipole layer (two parallel sheets charged equally and oppositely). A series solution to the Schroedinger equation has been done for a triangular barrier, and a computer program is being composed to calculate the reflectivity spectrum.

Neither of these models consider the image potential experienced by the finitely charged electron as it approaches the surface of a conductor. By superimposing the image potential upon a rectangular-

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1. R.E. Thomas, J. Appl. Phys. 41, 5330 (1970)

Figure 2 - Electron Reflection Spectra for Rectangular Energy Barriers

potential-well model, MacColl² showed that this realistic addition results in a substantial reduction in the reflection coefficient. A study is being made of superimposing a surface barrier onto MacColl's model.

B. BASIC SURFACE EXPERIMENTS

A study is being conducted of the chemistry of tungsten oxide collectors. A number of tungsten oxide collectors, each at a different stage of activation, are to be studied by ESCA to determine the types of oxide present. The collectors were made by vacuum depositing a thick layer of tungsten oxide onto an etched polycrystalline tungsten substrate.

II. PLASMA THEORY

A. CONVERTER THEORY

The modification of the plasma program to include electron temperature gradient iteration has been completed. The results show that the inclusion of the electron temperature gradient increases the ratio of particle densities at the emitter boundary and the collector boundary as well as affects the value of the arc drop. Inclusion of the electron temperature gradient makes it possible to obtain solutions for lower values of current. The present version of the program requires many iterations to obtain the final result. After the iteration procedure is improved, calculations will be made over the range of interest. The modification of the program to include a second vapor in the interelectrode space is in progress.

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2. L.A. MacColl, Phys. Rev. 56, 699 (1939)

B. ENHANCED MODE CONVERSION EXPERIMENTS

A series of tests were conducted using a pulsed triode converter with an electropolished arc cast tungsten emitter, a deposited tungsten oxide collector and a four wire (3 mil diameter) molybdenum grid. The spacing between the wires was approximately 80 mils, with the grid located 50 mils from the collector. The interelectrode spacing could be varied from 100 to 200 mils.

Pulsing experiments were carried out in argon-cesium atmospheres. A diagram of the experimental arrangement is shown in Figure 3. The minimum pulse width was limited to approximately one microsecond (this limit was most probably dictated by the inductance of the pulsing network). A pulse repetition rate of three kHz optimized the enhanced operation of the converter. After each pulse nearly constant voltage plasma decay rate was observed at each point of the I-V curve. The decay time was increased (and thereby the thermionic current increased) as the argon pressure was raised. At $T_E = 1465$ K, $T_C = 835$ K, $d = 100$ mils, $P_{Cs} = 0.16$ torr and $P_{Ar} = 33$ torr, preliminary results showed a power gain of 23 mW for 15 mW input. Maximum discharge voltages were limited by the plasma to 14 volts.

III. CONVERTER DEVELOPMENT

A. LOW TEMPERATURE CONVERTER DEVELOPMENT

1. Electrode Screening

Recently, the study of alkaline earth oxides as collector materials was extended to include SrO and CaO. As with conventional BaO cathodes, the oxides were formed by thermal decomposition of a

Figure 3. Schematic Representation of the Operating Grid Triode Converter

sprayed film of the carbonates. This is the most convenient method for initial screening. However, it was realized from the beginning that such thick films have excessive bulk resistance for use in converters. Because of the encouraging results obtained with the latest BaO collector (see Progress Report No. 4) the experiments during this month were aimed at studying evaporated films of the oxides. These can easily be made with thicknesses in the 100 Angstrom range to ensure the necessary low bulk resistance.

Both BaO and SrO were evaporated from platinum strips sprayed with the carbonates. The work functions of both SrO and CaO were measured without exposure to air after evaporation. The work function of BaO was also measured after exposure to air. The following preliminary results were obtained:

- Barium Oxide - The bare work functions of two unexposed samples were 1.40 and 1.48 eV at 550 K. The work function of the air-exposed samples was 1.74 eV at 800 K. The work function values in both cases were less temperature dependent than in samples produced by the decomposition of sprayed carbonates. Both the absolute work function values (in the 1.4 to 1.5 eV range) and the relative temperature independence are in good agreement with earlier results by the Naval Research Laboratory Group.

On exposure to cesium the behavior of the samples differed from that of sprayed cathodes. While the work function of the air-exposed sample was reduced to the value of the non-exposed samples (about 1.4 eV), there was no beneficial effect of cesium on the 1.4 eV value. Even alternate exposure to cesium and

oxygen, which had been found so effective with sprayed cathodes, did not affect the work function value at all. One possible explanation is that the surface structure of the evaporated films exerts smaller binding forces on cesium.

- Strontium Oxide - The bare work function of SrO was 2.22 eV, which is in good agreement with published values. Cesium exposure lowered this value to 1.42 eV at 500 K (i.e., there was a considerable improvement, but the absolute value was still no better than barium oxide). Further study of the effect of higher cesium pressures is indicated.

Some exploratory experiments have been made with the BaO-Ag (Cs) system. The reason for this is that the Cs_2O -Ag system is known to have the lowest work function (< 1 eV) observed in any material. By replacing Cs_2O with the thermally stable BaO it was hoped that a similar configuration to Ag-O-Cs could be obtained. Replacing cesium with barium would obviously increase the work function, but even an increase of several tenths of an eV would still represent an acceptable value.

The formation of Ag-O-Ba was attempted by two different approaches. In the first, BaO was evaporated onto a silver substrate; in the second, silver was evaporated onto an evaporated BaO substrate. In both cases, subsequent cesium and oxygen processing was tried. The initial results were somewhat surprising. It had been expected that the silver would have either a detrimental or a beneficial effect. In fact, the performance did not differ significantly from that of BaO without silver. This study will be continued, since the

incorporation of silver, even if ineffective for lowering the work function, may produce a useful increase in electrical conductivity.

2. Converter Evaluation

a. Tungsten Oxide Converter No. 122

This standard variable spacing converter used a deposited tungsten oxide on a sandblasted tungsten substrate collector. The emitter was electropolished tungsten. After cesiation, the cesium tubulation appeared to be plugged, trapping the cesium in the converter. The emitter flange was heated to 1020 K and the collector to 530 K which finally cleared the plug and allowed the cesium to condense in the reservoir.

The lower temperature performance of the converter was relatively poor ($V_B = 2.3$ to 2.4 eV, with collector temperatures of about 650 K). There was only a small amount of oxygen supplied to the emitter. At higher emitter temperatures, 1800 to 1900 K, with 750 K collector there was still evidence of oxygen for the emitter and the barrier index had improved to 2.2 eV. It is possible that the treatment used to unplug the cesium tubulation depleted the oxygen concentration on the collector. Further testing will study higher collector temperatures.

b. Titanium Oxide Converter No. 123

As part of Thermo Electron's studies of metal oxide collectors, a standard variable spacing converter was constructed with an oxidized titanium collector. The purpose of this converter was to reproduce

the results of Professor J. P. David (University of Marseille, France), presented at the Eindhoven Conference.

The collector was fabricated by nickel brazing a titanium disk to a molybdenum cap which, in turn, was Cu-Ni brazed to the usual nickel collector body. The complete assembly was then oxidized at 725 K for four hours in one atmosphere of oxygen. Except for the electrode surface, the assembly was then final machined. The emitter was electropolished tungsten. Predegassing was carried out with 525 K as a maximum collector temperature. Outgassing was completed with the same temperature restriction.

Initial testing in the lower mode gave collector work functions of about 1.5 to 1.6 eV at 500 to 600 K. The performance of the converter was relatively poor ($V_B = 2.3$ eV) with no evidence of an oxygen supply for the emitter. At 650 K the collector work function improved to 1.45 eV. At higher collector temperatures (850 K) and higher emitter temperatures (1800 - 1900 K), the barrier index improved to 2.15 eV. Since there was no evidence of an oxygen supply for the emitter, spacings of 10 mils or less were required.

B. HIGH EFFICIENCY CONVERSION EXPERIMENTS

1. Lanthanum Hexaboride Converter No. 121

Construction of a standard variable spacing converter, which includes provisions for oxygen admission through the collector via a silver tube (see Figure 4), was completed and outgassing started. The emitter is electropolished arc cast tungsten and the collector is lanthanum hexaboride.

Figure 4 - Cross Section of the Standard Variable Spacing Converter with Silver Tube for Oxygen Addition.

Heating the silver tube showed an initial outgassing pressure surge followed by a slow clean-up. Further heating gave evidence of good pressure control by means of the tube temperature. However, continued heating caused a leak to develop in the silver tube assembly. The assembly is being cut apart to determine the cause of the leak.

IV. COMPONENT HARDWARE DEVELOPMENT

A. HOT SHELL

Testing of the General Electric and the two Kanthal A-1 hot shells continued at TRW. A vacuum of less than 10^{-7} torr continued to be maintained for all three hot shells, with the exposed surfaces at a temperature of at least 2400 F (1589 K). The test for the General Electric hot shell now exceeds 4800 hours, and the tests for the two Kanthal A-1 hot shells now exceed 2000 hours.

B. COMBINED OXYGEN/CESIUM RESERVOIR DEVELOPMENT

Initial experiments with the external reservoir converter encountered temperature limitations associated with the valving. This design is being modified for improved operation.

V. SYSTEM STUDIES

Thermionic topping cycle studies in support of the EPRI advanced cycle systems evaluation continued. A reference converter assembly (including heat pipe, hot shell series connectors, mounting hardware and thermionic diode) has been designed. Detailed drawings of the converter assembly have been made and sent to potential vendors for quotation. System analyses are continuing.

VI. ORDERING GAINS

No work was performed on this task during this reporting period.

FY 1976 THERMIONIC MILESTONES

<u>ITEM</u>	<u>TARGET DATE</u>	<u>ACTUAL DATE</u>
1. Construct guarded, variable spaced test converter	Sept. 1975	Sept. 1975
2. Parametric analysis of surface ionization triode	Nov. 1975	
3. Incorporate barium oxide collector into thermionic diode	Dec. 1975	Nov. 1975
4. Screen rare earth oxides for low work function collector	Feb. 1976	
5. Compare effects of elementary and detailed boundary value assumptions on converter analysis	April 1976	
6. Test thermionic diode with cesium oxide reservoir	July 1976	
7. Summary report on hot shell alloy development	Sept. 1976	
8. Report on thermionic topping of organic Rankine cycle	Oct 1976	

Task Identification

ERDA Tasks - IA, IIA, IIIA, IV & V

NASA Tasks - IB, IIB, IIIB, & VI