TYPES OF THERMIONIC POWER CONVERTERS AND CURRENT MATERIALS LIMITATIONS

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Thermionic power converters are static energy conversion devices that transform heat directly into electrical energy (figure 1). A thermionic generator consists of one or more of these thermionic converters coupled to give the desired power output. A thermionic generator has a number of distinct advantages over dynamic conversion devices. Some of these advantages are:

a. Rotating equipment is not employed.
b. Liquid-vapor phase problems do not exist.
c. Separators for fluids are not required.
d. Frictional losses due to bearings are not present.

Some of the disadvantages of thermionic generators are:

a. Individual converters are low voltage, high current devices.
b. A large number of converters must be sequentially arranged to obtain useful voltage.
c. Power losses in leads and in the converters can seriously cut useful power output.

Thermionic generators can be operated from any primary heat source. For low power levels, i.e., three kilowatts or less, solar energy looks very promising. For higher power levels a nuclear heat source is required. In large nuclear thermionic generators of fifty kilowatts or more, a liquid-metal cooled reactor and pumping equipment will be required to dissipate waste heat to a radiator surface.

Thermionic power converters can be categorized for reference purposes in several different ways. We have chosen to classify thermionic converters according to the methods of neutralization space charge. On this basis the most frequently discussed are:

a. Vacuum Close-Spaced and b. Cesium Gas Filled

Other breakdowns that emphasize the type of emitters employed are just as meaningful. In any case, electrons are emitted from a heated surface (cathode), move through an inter-electrode spacing, and are collected on an anode. Electrons are returned to the cathode through an external load.

Three important aspects must be immediately considered in all thermionic converters:

a. The cathode must emit an abundant supply of electrons.
b. Evaporation of atoms from the cathode surface should be negligible.
c. Electronic space charge build-up in the inter-electrode spacing must be eliminated.

Search for solutions to these problems account for the number of programs being investigated on thermionic power converter technology.

The cathodes of thermionic converters must be operated in excess of 1100°C to obtain a satisfactory current density from the emitter surface. In addition, the emitter must be compatible with the cesium environment around it and have a low evaporation rate. Emitter materials currently being investigated are (see figure 2):

a. Simple metals (molybdenum and tantalum)

b. Tungsten impregnated with barium oxide

c. Solid solutions of mixed carbides (uranium carbide-zirconium carbide)

The physical and chemical properties of the basic metals are fairly well defined. The investigations on the more complex emitter materials have been based on trial and error experiments. A systematic search for high electron emission compounds should be continued.

The vacuum close-spaced converter which has been under extensive investigation since 1957 was the first attempt to solve the electronic space charge problem. This type of converter looked promising provided a physical spacing of 0.0005 inch or less could be maintained between the cathode and anode. This has been a difficult engineering feat because temperatures on the cathode surface were 1100°C. In addition, there were other problems that arose:

a. Relatively high barium evaporation rates from the cathode

b. Deposition of barium on cathode-anode spacers

c. Different expansion rates for impregnated tungsten and tungsten

d. Warpage of cathode followed by shorting of converter

e. Pulverization of cathode-anode spacers

f. Inability to remove copper from the emitter (Copper is initially added to improve cathode machineability)

The vacuum converters average approximately 3 percent efficiency and a lifetime of 40 hours.

Use of positive ions in the inter-electrode spacing of thermionic converters permits a wider separation between the cathode and anode. If thermionic converters are to be mass produced, this is an important consideration (figure 3). Almost any positive ion will suffice to neutralize electronic space charge provided materials compatability is satisfied. Ideally, an inert gas or mixtures of inert gases should be used; however, cesium is usually employed because of its proneness to ionization. In experimental thermionic converters cesium is admitted from a temperature controlled well. Experimental thermionic converters regulate cesium pressure in the inter-electrode spacing. In thermionic converters with high work function cathodes and when operated at high temperature, most of the cesium ionization occurs by contact ionization with the cathode surface. In lower temperature cesium filled converters and in those that employ low work function cathodes, much of the ionization occurs by collision processes. The operation of thermionic converters at high temperature and the introduction of a corrosive alkali metal adds a completely new problem to thermionic power converters (figure 4). All converter components, anode, cathode, seals and envelope must be resistant to cesium corrosion. To date, one of the major problems has been in seals. In fact, most cesium filled thermionic converter failures can be blamed on corrosive destruction of seals by cesium.

So far as known, cesium filled power converters have never been operated in excess of 600 hours. Failures to date can largely be blamed on seal failures and loss of cesium in the inter-electrode spacing. Efficiencies are tricky to quote and often misleading unless lifetime is also quoted; however, 15 - 17 percent is not uncommon.

In the lower power ranges of 3 kilowatts or less, thermionic converters may find application in solar generators. In the higher power levels up to megawatts, thermionic converters appear very promising for use with nuclear reactors. Converters may be operated as an intimate part of the nuclear reactor or exterior to the reactor. The radiator of a liquid metal cooled reactor is a good location for thermionic converters. The converters can extract heat from the liquid metal plus serve as a very good protection to vulnerable liquid metal tubing. Thermionic generators are three to five years away from initial application in aerospace vehicles although experimental test flights could be undertaken in approximately two years. Low power solar heated generators look most feasible within this time period. To attain the goal of thermionic converter application in aerospace vehicles within the three to five year period, extensive research is required on:

a. High temperature seals
b. Low evaporation rate emitters

A better understanding of the high temperature chemistry of cesium in the environment of the individual thermionic converters is mandatory. Coincident with the cesium investigation, search for low evaporation rate materials should continue and fundamental investigations to improve life expectancy of existing cathode materials should be made.

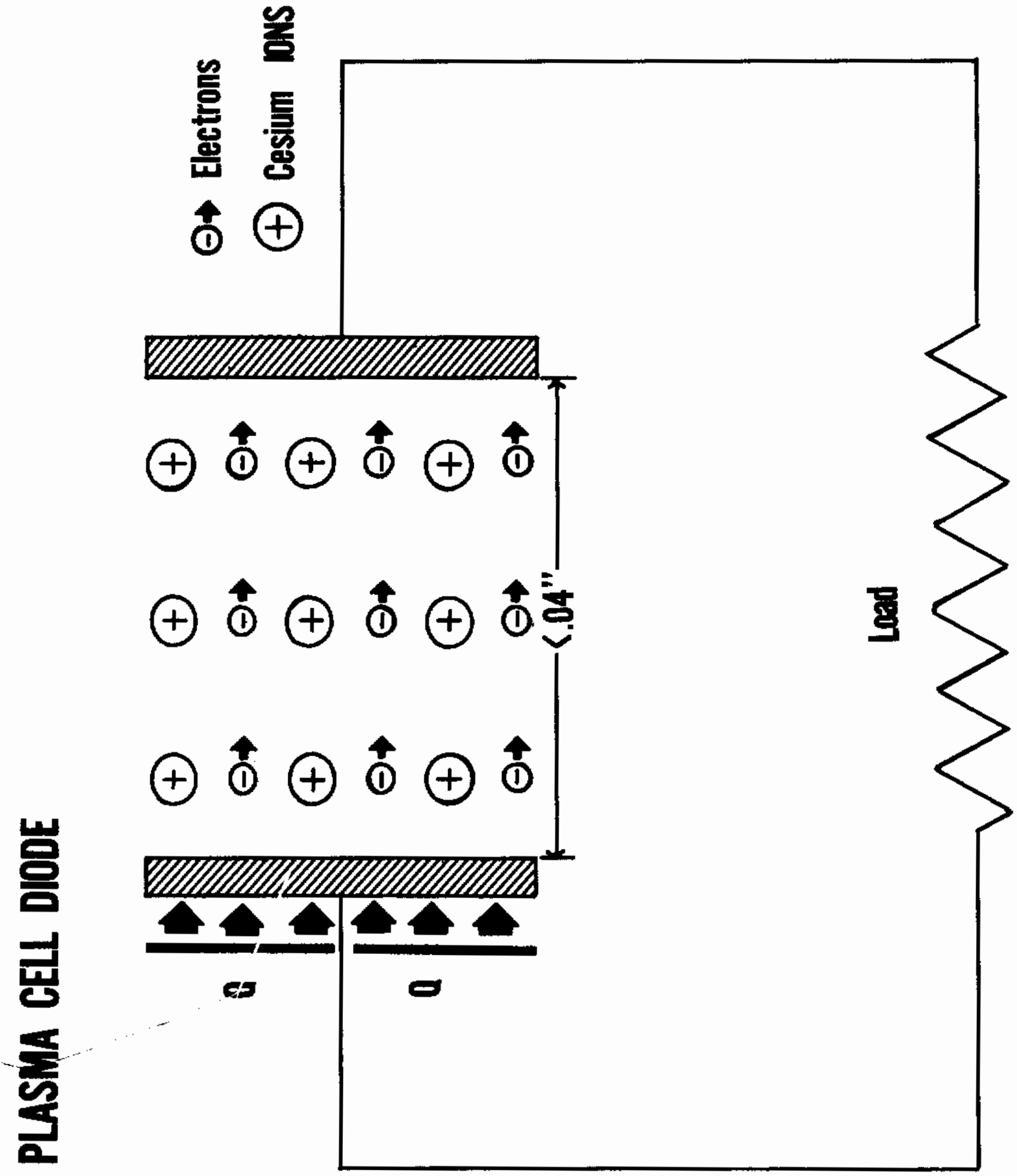

Figure 1.

EMITTER MATERIALS

EXTENSIVE RESEARCH		LIMITED RESEARCH
Simple Metals	W Mo Ta	Re LaB_6 Borides, Nitrides, Carbides
Oxides	Ba Sr Ca	
Carbides	U-Zr	

Figure 2.

SPACE CHARGE NEUTRALIZATION

EXTERNAL RESEARCH	LIMITED RESEARCH
Vacuum	Neon-Argon
Cesium	Fission Fragments
	Rubidium

Figure 3.

INSULATOR	WELDS	BRAZES
Al_2O_3	ELECTRON BEAM	Cu**, Ag**, Au
BeO	Cu-Mo	Binders (Zr)
HfO_2	Ta-Cu	Ta-UC-ZrC
	Cu-Steel	
	Cu-Fe/Ni Alloys	

* Electron Beam Used To Prevent Poisoning Of Converters

** Ag, Au Attacked By Cs - Mg

Figure 4.