SOLID-STATE ISOTOPIC POWER SOURCE
FOR COMPUTER MEMORY CHIPS

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ABSTRACT

Recent developments in materials technology now make it possible to fabricate nonthermal thin-film radioisotopic energy converters (REC) with a specific power of 24 W/kg and a 10 year working life at 5 to 10 watts. This creates applications never before possible, such as placing the power supply directly on integrated circuit chips. The efficiency of the REC is about 25% which is two to three times greater than the 6 to 8% capabilities of current thermoelectric systems. Radioisotopic energy converters have the potential to meet many future space power requirements for a wide variety of applications with less mass, better efficiency, and less total area than other power conversion options. These benefits result in significant dollar savings over the projected mission lifetime.

INTRODUCTION

Placing miniature power supplies right where they're needed on integrated circuit chips is a quick and efficient way of getting electrical power to a circuit's microscopic components. This goal now seems within reach with the construction of the tiny, thin-film radioisotopic energy converter or REC that generates electricity.

Traditional lead-acid batteries are made from plates of lead and lead peroxide immersed in a sulfuric acid solution, called an electrolyte. Charged atoms, called ions, flow through the acid within the battery from one plate to another, setting up an electrical imbalance that causes electrons to flow through wires attached to the battery terminals and completing the circuit. These batteries are heavy and corrosive.
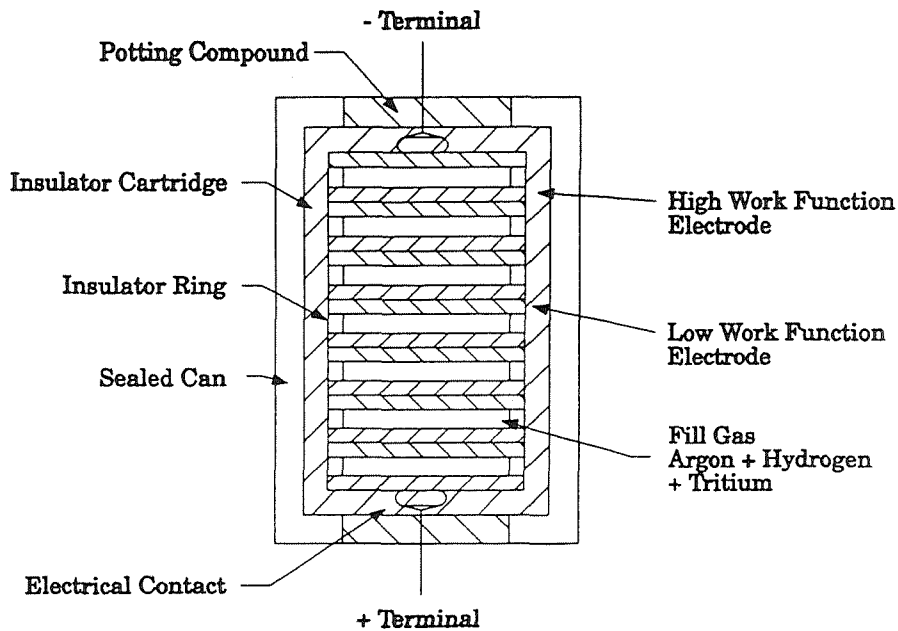

FIGURE 1. Contact Potential Gas Ionization Type.

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Interest in non-chemical space power systems has been rekindled with the recent ambitious manned space missions planned by NASA's Space Exploration Initiative. Deep space missions will require more energy than is practically available from chemical systems.

The operation of a contact potential cell was first demonstrated by Kramer in 1924 (Brown 1992a) while new developments have been the subject of much research (Brown 1992b). When a gas is irradiated by beta particles, ionization results. If this occurs in an electric field, such as produced by the contact potential difference of two dissimilar metallic electrodes (Figure 1), which are electrically connected through an external conductor, the ions will migrate to the electrode of opposite charge and conduction through the gas takes place. The electrical energy delivered to any external load is a result of the ionizing energy of the beta particles. The contact potential difference enables the neutralization of ions and the transfer of their charge to the circuit to take place. Efficiency is limited to 1% by charge recombination, leakage current, and space-charge effects but long life of 20 years is easily achieved.
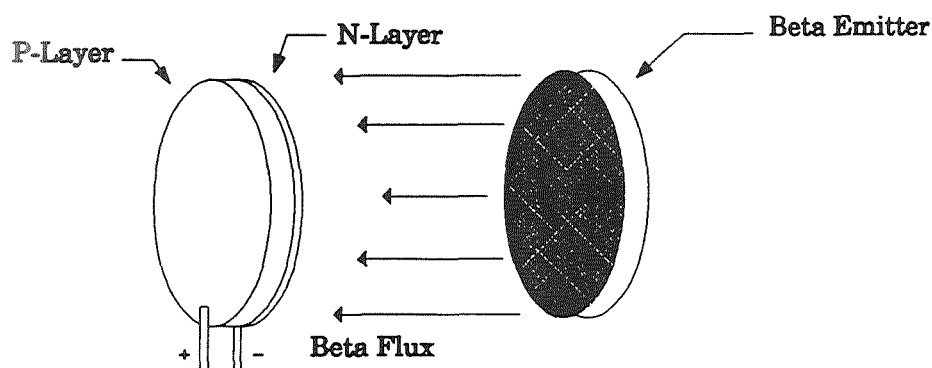

FIGURE 2. Basic Approach to Betavoltaic Energy Conversion Consisting
of a Source Coupled to a Semiconductive Junction Device.

The first work on p-n junction converters was reported by Rappaport in 1954 (Linder 1956), since then betavoltaic p-n junction batteries have been used only as a source of power in the heart pacemaker, where power requirements are on the order of micro-watts (Olsen 1972). Figure 2 shows a straightforward approach to a betavoltaic p-n junction energy converter; a planar source of beta emitting material is coupled to a planar p-n junction device. The n-face and p-face are respectively the negative and positive terminals of the single cell power source. Utilizing the internal electric field of the junction, the radiation energy is converted directly into electrical energy, in much the same manner as a solar cell converts photons of light into electricity (Olsen 1974). Efficiency is good on the order of 25% and fairly reliable using low power isotopes in the microwatt range but radiation damage to the junction seriously limits the working life of this type of device, when built with any power above one milliwatt, to only a few days.

I should also mention the most widely used type of nuclear battery which is called the radioisotopic thermoelectric generator (RTG). This type of device utilizes the heat produced by large amounts of radioactive material with a thermo-couple to generate electricity. This type of device is limited to only 6 to 8% efficiency and requires high operating temperatures in addition to the fact that much shielding is necessary because of the type and amounts of radioactive material used. However, these devices are reliable and have been used repeatedly by NASA as well as other agencies.

THE RADIOISOTOPIC ENERGY CONVERTER (REC)

The nonthermal thin-film isotopic energy converter is a hybrid contact-potential/betavoltaic device. It is made up of alternating thin-film layers of low work-function metal (Figure 3), isotope laced semiconductor media, and a high work function metal. Beta particles emitted from the source traverse the media losing energy and creating electron-hole pairs. Those carriers within a diffusion length of the junction will be swept across the gap contributing a current. A United States Patent was granted on this innovative approach to radioisotopic decay energy conversion February 11, 1992, USP #5,087,533.

The embodiment shown here in figure 3 consists of a thin film layer of cesium metal on which a second layer of selenium is deposited. Other materials will also work in place of the selenium. This selenium layer is loaded with tritium for this configuration although any suitable isotope will work. The third or final layer is of platinum metal which yields a composite foil 0.001 mm thick and will deliver 4.4 volts continuously.
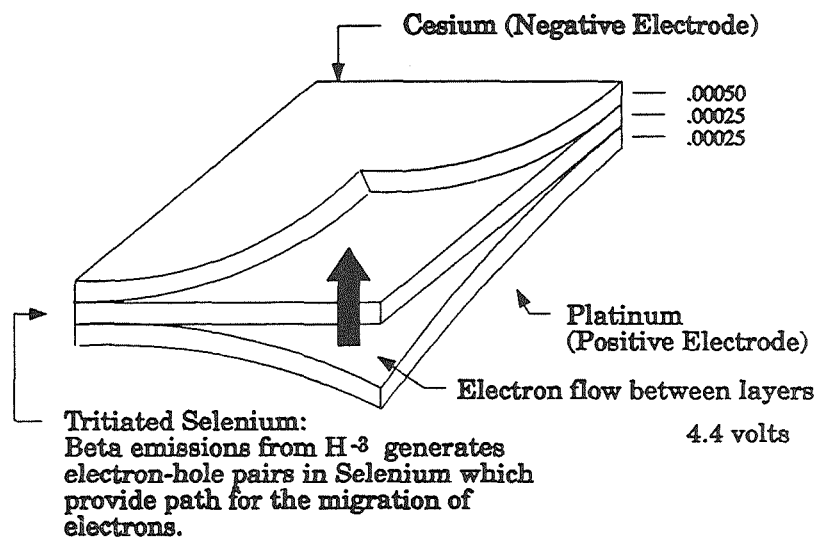

FIGURE 3. Radioisotope Electric Converter (Paper-Thin Layers
are Shown Peeled Back for Illustration).

Just as a solar cell converts light energy directly into electrical energy, the REC converts radioactive decay energy directly into electricity. The new technology of the REC works on the same principle as traditional batteries only the ions are not generated by chemical reactions. Rather, the acid solution or electrolyte is replaced by a semiconductor medium that is ionized by the absorption of radioactive decay particles emitted from a radioisotope homogeneously dispersed throughout the semiconductor itself. That is to say, the semiconductor is doped with the radioisotope. The semiconductor medium is a thin-film and conducts ions between metal electrodes typically made of cesium and platinum. Versions of the REC develop a potential difference of 1 to 4.5 volts DC between the electrodes (depending on the type of electrodes used) from a single cell and a few milliwatts of power per square centimeter.

One embodiment of the REC yields 4.4 volts DC from a foil only 0.001 mm thick while another embodiment produces 9 volt DC from a foil .045 mm thick. The current is determined by the isotope used and the surface area of the foil. This foil may be rolled into tubes, spirals or be cut into virtually any shape. Calculations show a specific power of 24 watts per kilogram with a 10 year working life is achievable for a 10 watt device (NASA 1991). Based on recent experimentation the efficiency is estimated to be on the order of 25% thermal to electric, which is three times greater than the 8% capability of current thermoelectric systems.

The REC is superior to betavoltaic devices of the p-n junction type because the REC design does not subject the voltage mechanism to radiation damage; superior to the contact potential difference converter because without a gas the REC is not susceptible to space charge effects while ion recombination is limited by the narrow

media gap; and superior to the RTG by operating at low temperatures with greater efficiency, lower weight, and reduced health dangers.

The possibility of using relatively simple manufacturing techniques to fabricate these miniature, thin-film RECs at low cost suggests a variety of applications. Here at IsoGen, we are investigating how to deposit these devices directly onto integrated circuits to provide onsite power for computer memory chips.

In concept, the REC offers several advantages over batteries made with liquid electrolytes. The REC will last much longer due to the fact that radioisotopic energy is several orders of magnitude greater than chemical energy. They also operate over a broader temperature range than batteries with electrolytes made from liquids, which may freeze in extreme cold or boil in extreme heat. Some batteries on the market use a gel or a solution suspended in plastic as their electrolyte, but none is totally solid state. The REC may be the first totally solid state battery.

"Smart" credit cards equipped with a tiny computer chip to keep track of a user's banking records as well as such other information as medical history are being tested in Europe and Japan. The REC could run smart credit cards, cardiac pacemakers, possibly even artificial hearts or other electronics that do not require large amounts of power. New applications will be developed around this new long life portable power source that we can only dream of today.

Beta-Conductivity

Beta-conductivity is a phenomenon evidenced by the increase in electrical conductivity of a material after the absorption of ionizing radiation. This effect is attributed to the increased number of free electrons generated by absorption of the ionizing radiation. Of course, recombination of the charge carriers does occur, however, during the time these carriers are free in the material, the conductivity can be greatly enhanced. We minimize recombination by using very thin layers of the ionized material in the REC.

For a material in which one type of carrier predominates, for example electrons, the change in conductivity with irradiation can be expressed as (Brown 1990b):

$$\Delta\sigma = \Delta n e\mu + e n\Delta\mu \qquad (1)$$

where $\quad \Delta\sigma$ is conductivity change,
Δe is change in free carrier density,
e is electronic charge,
μ is carrier mobility, and
$\Delta\mu$ is change in carrier mobility.

"Beta-conductivity gain" may be defined as the number of inter-electrode transits that can be made by an electron in a conductor before the beta-generated "hole" is eliminated by recombination. For this case where one type of carrier predominates, the gain is expressed as (Brown 1990b):

$$G = \chi\mu^{V\lambda-2} \qquad (2)$$

where $\quad \chi$ is carrier lifetime,
V is applied voltage, and
λ is spacing between electrodes.

338

Principles of Operation

It is presumed that free electrons are retained in a metal by the forces of attraction between two unlike charges, since there must be as many positively charged atoms as there are free electrons. An amount of work must be performed to remove an electron from the surface of any metal called the work function of the material, and of course, this value may be calculated. But for this discussion it is sufficient to say that the work function of most elements, including the metals have been measured and tabulated in suitable reference books. Typically, work functions range from 1 eV (easiest to remove) to 5.5 eV (most difficult) for metals.

When two metals of different work functions, say cesium and platinum, are brought into electrical contact (by direct contact or through a conductor) an electrical potential difference is established as discovered by Volta in 1797. This contact potential difference is the result of the difference between the work functions of the two metals. The sign is determined by the fact that the metal with the largest work function gives up electrons the least readily and becomes the more electronegative.

An amount of work must be performed on a neutral atom to remove electrons (ionize the atom). This work manifests itself as increased potential energy and may be utilized to do work before allowing the electron and ion to recombine.

The Betavoltaic Effect may simply be defined as the conversion of ionizing radiation to electrical energy by a material or combination of materials. Radiation that is absorbed in the vicinity of any potential barrier will generate separate electron-hole pairs which in turn flow in an electric circuit due to the Voltaic Effect. Of course this occurs to a varying degree in different materials and geometries.

Figure 4 is a representation of a basic betavoltaic converter and demonstrates the characteristics of the REC. Electrode A has a positive potential while electrode B is negative with the potential difference provided by the Contact Potential Difference of the dissimilar metals. An electric field exists between the electrodes, a zone we will call the junction. The junction between the two electrodes is thus comprised of a suitably ionizable medium exposed to decay particles emitted from a radioactive source.
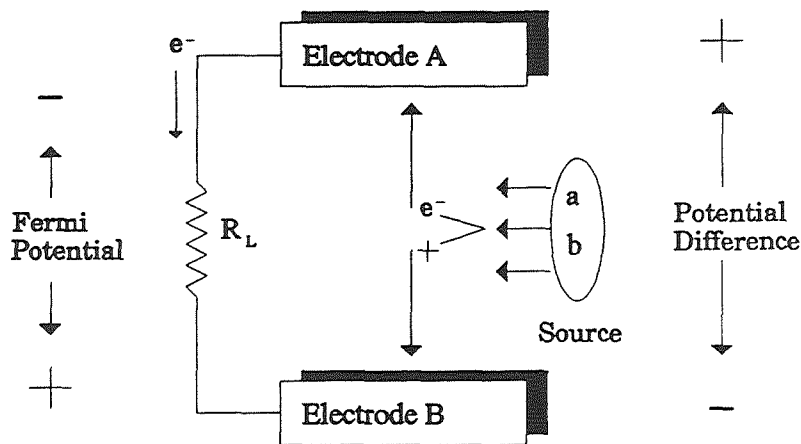

FIGURE 4. Betavoltaic Converter.

In general, the introduction of ions from any source into an electric field will generate electricity in accordance with well known physical principles and may be satisfactorily explained in terms commonly associated with the Volta Effect. The energy contributed to such a circuit does not come from the ions themselves but rather from the work done on the circuit to generate the ions, known as the ionization potential of that particular material.

Neither the electric field, the electrodes or the medium between the electrodes contribute any energy in the Voltaic Effect. The energy is contributed by the ion generator whether this mechanism is chemical, electromagnetic or nuclear is irrelevant. Modeling for the REC has been generated and published (Brown 1990a).

CONCLUSION

The REC is a current generating device including a pair of electrodes of electro-chemically dissimilar materials separated by a space filled with a solid medium having a relatively high dielectric constant and a relatively low ionization potential. Current flows in an external circuit coupling the two electrodes together when the solid medium is ionized. A suitable radioactive material is mixed or dispersed in the solid medium to provide the ionizing flux.

The REC could be a less toxic, longer lasting alternative to conventional chemical batteries, and most likely to compete with button cell batteries to power small electronic items. Such a device could have a broad range of applications, from portable power supplies for integrated circuits to information processing, and nonpolluting generators in portable phones. The REC's lightweight, durability, and lack of corrosiveness also make it a natural candidate for space flight.

Market surveys have been conducted by the nuclear industry in the past and the conclusion has been that there is a need for a long-life radioisotope nuclear battery. Economic studies indicate that the REC could be economically competitive with chemical batteries for applications requiring lifetimes of over two years at remote locations where the expense of charging or changing batteries is significant. Applications where the inaccessibility after implantation is a consideration that leads to the selection of an REC due to its superior reliability and life.

ACKNOWLEDGMENTS

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