Nano-Hetero Structure for direct energy conversion

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ABSTRACT

The direct conversion of nuclear energy becomes possible in hetero-nanostructures. To convert the kinetic energy of the fission product into electricity it has to be created a nanostructure formed from a repetitive conductor-insulator structure generically called "CIci".Its operation is based on the difference of electron shower intensity between the two conducting materials which makes that the electrons generated in the first conductor to pass through insulator and absorb in the second conductor, while this one producing a very small shower to pass in the next conductor so the conductors are polarizing. The conversion efficiency of such structures may be higher than 80%, and can be improved by quantum effects. To deliver the harvested energy outside the reactor zone a cascade of DC/AC and AC/AC micro converters have to be added at short distances inside. Because the fission energy transforms into electricity there is less energy left for heating the structure so the reactor will run cold. If superconductor structures is used the DC/AC converter may be achieved by using a SQUID Josephson junction. The direct nuclear energy conversion removes the actual thermo-mechanic devices with associated heat exchangers with higher efficiency, transforming the nuclear reactor into a solid-state electricity generator.

Keywords: nuclear fuel, hetero-structure, direct conversion, nano-structure,

1 INTRODUCTION

The direct energy conversion was a continuous subject of thinking starting from 1946, when the first patent [1] on this subject has been filed. In fact, the idea is much older, direct conversion being related to the radiation detection. The actual development of the beta batteries have used various versions of devices with ionizing radiation and charged particles [2].

The use of beta radioactive sources inside a capacitor like device to accumulate electricity were first proposed by 1956 [3] to produce low currents at high voltages, and recently retested [4].

The use of gamma rays to charge a capacitive structure by the photoelectric effect [5] was proposed by 1979 and has the advantage of higher power.

Another method of directly producing relatively low-voltage electrical power using a relatively high-energy radio-nuclide source is to irradiate a semiconductor device comprising one or a plurality of p-n semiconductor junctions connected in series or parallel [6, 7]. The p-n junction has high sensitivity to radiation damage and that is why they are using low-energy beta sources ^{147}Pr instead of ^{90}Sr. This concept is further developed in special applications of DoD [8].

The improved charged-particle powered electrical source [9] creating an improved battery for continuously-powered low-energy applications e.g., integrated microcircuits and/or sensors have been developed by 1997. The improved battery is powered by charged particles having kinetic energy that is transformed in electricity into a plurality of plate pairs or cells.

In the improved battery, the (relatively higher) kinetic energies of (relatively few) intercepted primary charged particles are incrementally converted to (relatively lower) kinetic energies of (relatively many) secondary electrons. These incremental kinetic energy conversions take place as the primary charged particles each pass through a plurality of cells comprising relatively thin plates. This relatively higher secondary electron yield in emitter plates will preferably be obtained by appropriate choices of plate materials, plate coatings, and/or plate geometry. Differential secondary electron emission from secondary emitter [9] plates and collector plates can also be attained through emitter plate coatings (such as magnesium oxide over platinum or carbon) which increases secondary electron emission relative to that of a collector plate comprising, for example, a thin (for example, about 100 nm thickness) carbon film. Still, another method to achieve a desired cell plate differential in secondary electron emission is through control of plate geometry to maximize the probability of interaction with primary charged particles and minimize self-absorption of secondary electrons in emitter plates. Additionally or alternatively, collector plate geometry may be controlled to minimize the probability of interaction with primary charged particles and maximize self-absorption of secondary electrons.

The preferred methods of making an improved battery [2] may also comprise an additional step of choosing materials for each collector plate and each emitter plate so that, cell collector Fermi energy levels exceed cell emitter Fermi energy levels for each cell. By this procedure the chosen cell potential is about 3-10 V [9].

2 THEORY

The most nuclear reaction, fusion or fission ends by transferring the mass defect into kinetic energy of the resultant particles. These particles interact with the matter stopping and transferring all their energy to lattices warming them.

A brief description of the stopping power [10] mainly characterized by the formula:

$$S = \frac{4\pi r_0^2 m\, c^2 Z_2 Z_1^2}{\beta^2}\left[\left(\ln\frac{2mc\,\beta^2}{1-\beta^2} - \beta^2\right) - \ln\langle I\rangle - \right.$$
$$\left. - \frac{C}{Z_2} - \frac{\delta}{2} - Z_1 L_1(\beta) + Z_2^2 L_2(\beta)\right] \qquad \text{Eq.1}$$

where r_0 is the Bohr's electron radius, the first parenthesis in the second term is the relative effect on stopping, I is the mean ionization energy, C/Z_2 is a shell correction, $\delta/2$ is the dielectric polarization correction , Z_1L_1 is the Barks effect for charge type corrections, Z_2L_2 Bloch effect.
Finally, the energy is mainly transferred to the electrons in the lattice and nuclei and after secondary interactions dominated by the electrons, the whole energy becomes heat. For exemplification purposes a multi-layers sandwich was developed, formed from the following layers: 1st U 100 nm; (2nd S 30 nm, 3rd Al 30 nm; 4th Li 40nm; 5th Pb 30 nm; 6th SiO 40 nm; 7th Mg 30nm; 8th I 100 nm; 9th CF_2 100 nm; 10th Th 100 nm; 11th Au 100 nm.

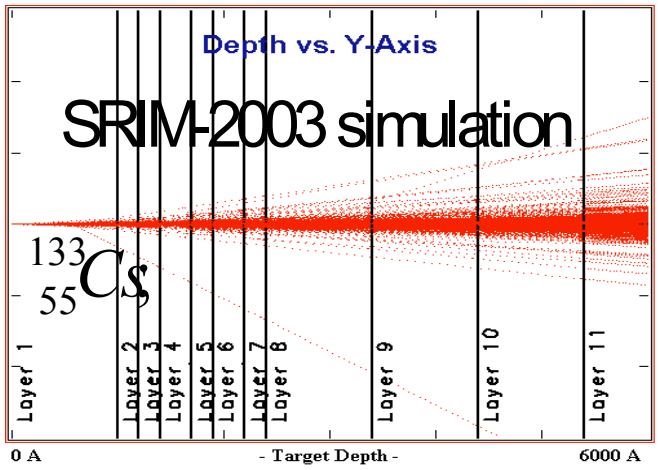

Fig. 1 – 100 MeV Cs stopping in a multi-material

The recoil implantation experiments [11] showed the capability of beams to deposit the kinetic energy into the recoil of other particles, nuclei and electrons opening various reaction channels.
The Monte Carlo simulations [12] presented in Fig. 1 shows the trajectories of Cs atoms one of the fission products in the material sandwich. The main stopping energy of moving particles in matter is due to the interactions with the electrons as Fig. 2 shows. During this process energy of 10 keV/nm is released. Considering that in 1 nm^3 there are less than 30 atoms and about 1200 electrons while only 3-4 molecules have been in the direct path of the particle. It turns that this energy is transferred to very few electrons removed by knockout from the molecular or atomic orbital.
All the range the ionization produces knock-on electrons that discharge their energy in showers down to energies of several eV. The free path in material is of several nm, comparable with the "Debye length", and is material dependent. Over the lengths of this size the electron trajectory has ballistic behavior if does not resonates with transitory quantum states due to the fact that the structure is far from equilibrium.
The simulation showed that the ionization is a complex dynamic function of energy, ion type, and material type. Fig. 2 shows a good differential ionization rate for all the type of materials, and its dependencies, which drives to case sensitive material optimization. It also shows that using a smart material combination is possible to create a nano-hetero-structure similar to those proposed for charged particles energy harvesting [2, 5, 9] which to harvest the energy of any kind of moving particle or radiation and to be used as nuclear fuel tile.

3 DISCUSSION

3.1 The electricity harvesting structures

The previous calculations showed that a structure created of high electronic density materials, where the ionization rate is high, and produces electronic showers, followed by an insulator, with a thickness comparable with the ballistic range through electrons to pass with no absorption, if their energy exceeds a level, of few eV. After this layer, a low electronic generator material which captures the electrons and drives to an external negative plot has to have a thickness such as to stop effectively all the electronic shower and emit no or minimal shower followed by an insulator. It is created a repetitive nano-structure composed of a Conductor – Insulator-Conductor Insulator (CIci) module. Between the two conductors of the

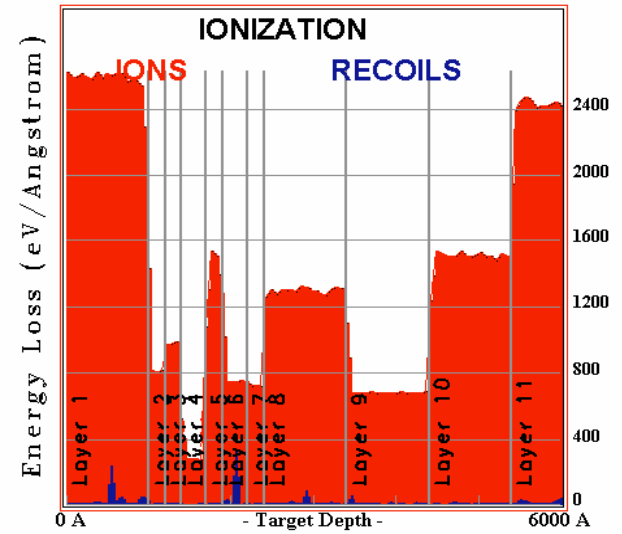

Fig. 2 – Ionization energy of 100 MeV Cs

"CIci" structure the electric charge accumulates. There are two basic potential electric connection types possible of being used: the parallel connection, where all the conductor of a kind are connected together, and this delivers lower voltages in the mV domain, given by the breakdown voltage admitted by the insulators. The serial connection, for domains where the moving particles field is constant at micrometric level, characterized by bi-polar conductive

particles oriented with the high electron yield conductor towards the source of moving particles deepen into insulator material and having two conductive layers, constituting the converter module plots. This material is forming a super lattice. The actual progress is made in binary super lattice building [13]with constituents included nanoparticles of gold, lead selenide (PbSe), palladium, lead sulfide, iron oxide, and silver, as well as triangular nano-plates of lanthanum fluoride. The resulting super lattices had a range of crystal structures to produce novel materials and generate novel properties by engineering material composition at the nanometer scales and by employing natural self-assembly phenomena to control self-assembly of the lattices by tailoring the shape of the nanoparticles and using different proportions of the two nanoparticle constituents.

3.2 Conductive and super conductive materials

The analysis of the heating process in nuclear fuel driven to the conclusion that the fast moving fission products are inducing in the insulator Uranium Dioxide ceramics electron showers of few micron range. The moving electrons interact with the lattice heating it.
To prevent heating it is necessary to cut the electron showers circuits and drive them through conductive materials in circuits where the total resistance to be significantly smaller.
The volume of the harvesting voxel is given by the conductivities of the two conductive layers, which have to

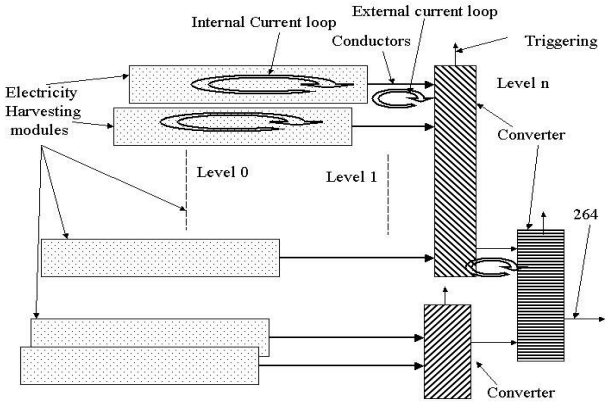

Fig. 3 Multi level based electric circuit

create an internal resistance much smaller than the previous one of the ceramics. This electrical structure reasons drives to the dimensional optimization of the direct conversion voxels.
Fig. 3 shows that each conversion voxel have to be accompanied by an electric converter DC/AC type realized in MEMS structure or micro-electronics having its impedance matched with the voxel.
The "CIci" structure has nanometer thick insulator, the maximum voltages will be less than 10 mV.

The level 1 converter has to bring this in the volts range, and another 2-3 stages are needed to get the power grid compatibility. The levels 1 output are connected into a level 2 adder, which has an AC/AC converter that increases the voltage and reduces the current in order to be applied to the next level. The final output level is compatible with the load requirements.
These modulus devices are connected in parallel at the tile level, in order to create the necessary redundancy. Due to nano-structure the controlled Josephson effect may be used to convert the electric DC power into alternate current K_J = (483 597.879±0.041)GHz/V [14]. The Andrew effect [15] may be applied to increase the conversion efficiency by quantum reflections in bi-materials, created at the minus pole, or inside bimetal polarized nano-beads.

There are three types of hetero-structures suitable for fission energy harvesting:

a) Having the fissile material U, Pu, Am not included in the structure but being surrounded by the harvesting structure thick as the range of the fission products. The ratio between the fissile material and the harvesting structure being dictated by the neutron criticality reasons.
b) Having the fissionable material mixed in the structure, mainly in the high density conductor structure by homogeneous or heterogeneous mixture
c) Having no fissile material in the structure, and shaped in tiles designed to stop by harvesting the energy of an external radiation like alpha particles from fission.

The usage of normal conductive materials drives to dimensions of the harvesting voxel in the range of mm^3 to cm^3, while the usage of superconductors may drive this volume up to dm^3.
To be used inside of a nuclear reactor volume the superconductor have first to exhibit a low absorption cross-section and to present low radiation damage. Another condition difficult to be achieved is the energetic balance, which simply means that the electric harvested energy to be smaller than the energy consumed to remove the thermal

Table 1 – Absorption cross-section [barn] of $PuCoGa_5$

	238Pu	239Pu	240Pu	242Pu
Pu	558	1017.3	289.6	18.5
Co	37.18	37.18	37.18	37.18
Ga	13.75	13.75	13.75	13.75
Amount	611.68	1068.23	340.53	69.43
Absorption decrease	91%	95%	85%	27%

effects inside, given by the particles direct heating and electric current heating effects. There are two super-conductive Plutonium based materials $PuCoGa_5$ and $PuCoRh_5$ with Tc around 18.5 K and 8.7K respectively is higher than any 5f electron configuration [16] for both materials, and equivalents based on Uranium, Americium, etc. The neutron absorption cross-section of Rh = 144 barns

makes it unusable in the nuclear reactor, while Ga is exhibiting a total absorption cross-section of only 2.5 barns, over ten times bigger than that of Oxygen and Carbon, but less than ½ of that offered by W and Ti. Table 1 shows the potential superconductor material using isotopic Plutonium combinations. The stability over time of Pu structures is analyzed because of Pu's 5 MeV alpha decay into U, which under recoil becomes a Frenkel defect in the lattice inducing vortexes in the superconductor and loosing the superconductivity [17]. Compared with other superconductors e.g. Y $(Ni_{0.8} Pt_{0.2})_2 B_2C$, $CeRu_2$, or $Yba_2Cu_3O_{6.95}$, it shows about the same sensitivity to radiation damage as layered superconductors or even to anisotropic ones like BSCCO ($Bi_2Sr_2CaCu_2O_{8+\delta}$) it exhibits same properties. What matters is the fact that an aging process is active driving to the modification of the material properties in time. The difference of usage of a superconductor structure inside a nuclear reactor will become a dynamic equilibrium between the rate of destruction of the superconductor structure under radiation and the rate of repairing it under the nucleation and growth of the interstitial loops and cavities [18]. To define a radiation resilient micro structure we have to further understand the role of 5f electrons [19] and superconductivity of the nano-structures. Hybrid materials and hetero-superconductive structures are possible if the cross-sections and radiation specific behavior are optimal. A similar process as quenching and re-crystallization may be used to create a dynamic superconductive layer floating inside the fissionable product in excess, until the nuclear reactor life is over.

4 CONCLUSIONS

The fabrication of nano-metric hetero-structures for the direct conversion of the radiation energy into electricity is an important development for the future power-sources.

The usage of the Actinides superconductors opens the way to the cryogenic nuclear reactors acting like ultra compact batteries with huge powers based on fission.

The development of energy harvesting panels for outer space applications and fusion energy harvesting using superconductors or normal conductors

The development of self-healable super-conductive or normal nano-hetero-structures will provide the longevity of the nuclear structure until all nuclear fuel is wasted.

The usage of the nano-hetero structure is pushing up the limits of power density in the nuclear fuel from actual about 0.2-0.5 [kw/cm^3] to 5000 [Kw/cm^3] theoretically predicted.

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