Nano-Nuclear Batteries

By Mark Paulson

The world of tomorrow that science fiction dreams of and technology manifests might be a very small one. It would reason that small devices would need small batteries to power them. Examination of the research paths and possible applications of nano-scale nuclear power devices will provide perspective on the technological and societal trajectory of nano-scale nuclear power devices.

There is an ever raging debate in academia of what exactly is and is not nano-technology and no technology hyphenated by “nano” escapes the debate. A simple and generally accepted criterion for labeling nanotechnology is given by Mihail C. Roco, Ph.D., a National Science Foundation Chair on the Nanoscale Science Engineering and Technology Subcommittee (NSEC) of the National Science and Technology Committee (NSTC),: one dimension of about one to 100 nanometers, designed through a process that exhibits fundamental control over the physical and chemical attributes of molecular-scale structures, and the ability to combine to form larger structures. While no person could currently go to Radio Shack and find a battery or device to put that battery in that meets Roco’s criteria, the path of nuclear battery research ends at such nano-scale power devices. This end is driven by the fact that the nuclear physics that makes such power generation possible occurs on a smaller dimensional scale than Roco’s 100 nanometer standard. In essence, such devices are theoretically only limited by our ability to manipulate and manufacture the necessary materials on the nano level.

It is of interest to examine the present research and physics of micro-nuclear batteries to glean the operational and structural design of future nano-nuclear batteries. Analogous to fossil fuel and a combustion engine there are two parts to every nuclear battery, a radioisotope source and a system that converts radiation from radioactive decay to power. Some radioisotopes emit charged α (He^{2+}), β (e^-) particles. The main advantage of a radioisotope “fuel” is it is “burned” at the rate of the isotopes half life. In other words, given a half life of 100 years, a nuclear battery would still produce half of its initial starting power after 100 years. There are two schemes of conversion that could be scaled down to make nano-nuclear batteries commonly called betavoltaics and self-reciprocating cantilevers.

The operation of betavoltaics is governed by several parameters. As shown in Figure 1, the betavoltaic effect is the generation of electrical potential due to net positive charge flow of the β-particle induced electron hole pairs (EHPs). When EHPs diffuse into the depletion region of the semiconductor pn-junction, the electrical field of the depletion region sweeps them across the depletion region[9]. Net power can be extracted because the resulting current is from n- to p-type semiconductor.

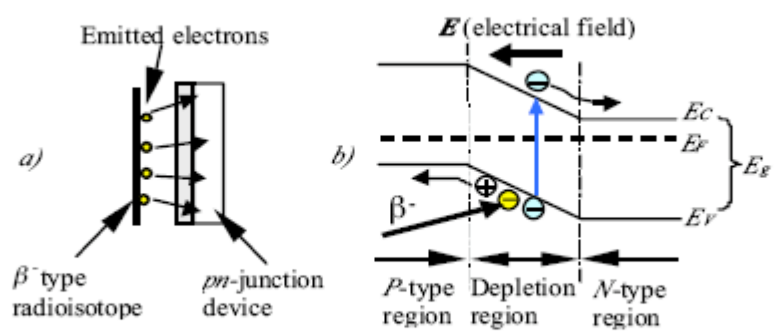

Figure 1 Betavoltaic effect a) Schematic diagram of betavoltaic battery b) Potential diagram for a betavoltaic effect [1]

Consequently a betavoltaic's performance depends on the energy of incident β-particles and the number of EHPs produced near the depletion region of the pn-junction[1]. The first micro-betavoltaics made use a planar pn-diode with the radioisotope electroplated to one side as shown in figure 2.

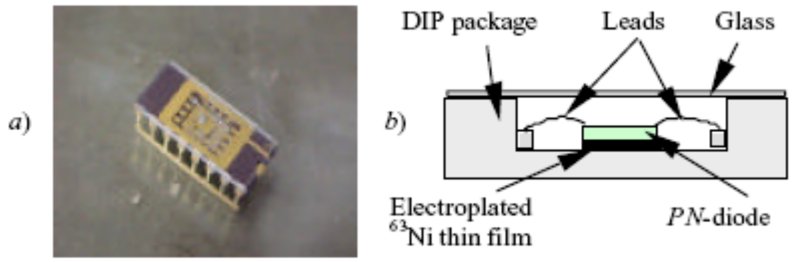

Figure 2 Betavoltaic micro-battery based on a planar Si pn-diode with electroplated 63Ni. a) Picture of a packaged sample. b) Configuration of the packaged micro-battery [1]

With further research it became possible to increase power by increasing the pn-junction area. Bulk-micromachining is used to fabricate the pn-junction device with an inverted pyramid array which forms reservoirs for a liquid radioisotope solution as shown in figure 3. A liquid radioisotope source is also desirable because it would be possible to refuel the betavoltiac[2].

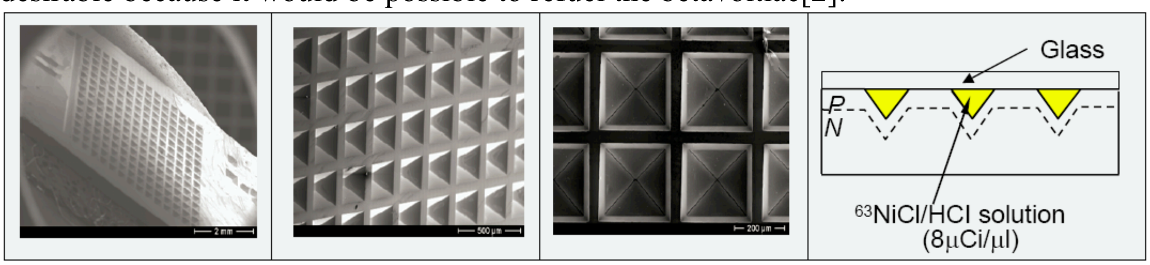

Figure 3 Betavoltaic microbattery based on a pn-junction device on a bulk-icromachined inverted pyramid array. Left three are views of the inverted pyramid array and the far right shows the configuration of Liquid 63NiCl/HCl solution in the inverted pyramid array [1]

The energy conversion efficiency of the β-particles in these betavoltaics is 0.5-1.0% producing on the order of nano-Watts of output power[1]. With further research it is expected that efficiency would increased and these currently micro-size betavoltaics could be made nano-sized.

The second possible nano-battery scheme, the self-reciprocating cantilever, is comprised of two components operating in cyclical manner. The central idea behind this oscillator is to collect the charged particles emitted from the radioisotope on a cantilever. By charge conservation, the radioisotope will have opposite charges left as it radiates electrons into the cantilever. Thus an electrostatic force will be generated between the cantilever and the radioisotope thin film. The resulting force attracts the cantilever toward the source. With a suitable initial distance the cantilever eventually reaches the radioisotope and the charges are neutralized via charge transfer. As the electrostatic force is removed, the spring force on the cantilever retracts it back to the original position and it begins to collect charges for the next cycle. Hence, the cantilever acts as a charge integrator allowing energy to be stored and converted into both mechanical and electrical forms[4]. Figure 4 is a schematic of the self-reciprocating cantilever system.

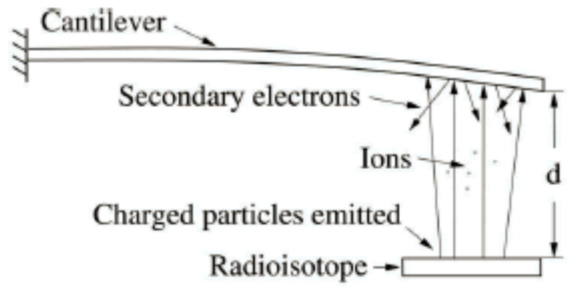

Figure 4 Schemetic of oscillator. The distance between the cantilever and radioisotope is d and changes through the electrostatic build up and discharge cycle [4]

The self reciprocating cantilever does not directly produce electric potential like betavoltaics but rather act as a charge integrator allowing energy to be stored and converted into both mechanical and electrical forms[4]. Currently only macro-scale oscillators have been made but, just as betavoltaics, size is only limited by the ability to manufacture the various components.

Driving the research of nano-nuclear batteries is the goal of using the devices as a power source in several types of applications. In the near term it is the rapidly expanding research of Microelectromechanical Systems (MEMS) with potential applications varying from sensors in airbags to lab on a chip modules and even optical applications. One reason that MEMS have not gained wide use is because they lack the on device power required for remote operation[4]. Another hurdle in MEMS implementation is having power source with the longevity and power density required for long term reliability[4]. Both of these obstacles could be removed with the use of micro-nuclear batteries. It stands to reason then, that as nanotechnology progresses to require on-board long life power sources, micro-nuclear batteries should be scaled down to nano-nuclear batteries. The long term goal of powering consumer devices such as cell phones, PDAs, and laptop computers is still far off. This is because the while nuclear batteries have a high power density they still could only produce nano to milla Watt power[12]. However, the most likely way in which a nano-nuclear battery would be used in a consumer device is to trickle charge a more powerful but shorter life battery such as a rechargeable Lithium battery.

Clearly the current research of nuclear batteries shows promise in future application of nano-nuclear batteries. With implementation of this new technology credible feasible, the total impact of the device must be considered. The largest concern of nuclear batteries comes from the fact that it involves the use of radioactive materials. This means throughout the process of making a nuclear battery to final disposal all Radiation Protection Standards must be met. The size of nano-nuclear devices is both good and bad in this consideration. On the one hand the small amount of radioactive material in a nano-nuclear batter would limit the possible radiation dose well below what is known to be harmful and that allowed by current law[6]. On the other hand, the possibility of exposure would increase because nano-scale material is inherently hard to physical contain. In the event that the radioisotope source of a nano-nuclear battery was release into the environment it would be near impossible to physically isolated because of it's size and in the worst case could be easily inhaled or ingested without any knowledge. Balancing the safety measures such as shielding and regulation while still keeping the size and power advantages will determine the economic feasibility of nano-nuclear batteries.

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References

[1]Amit Lal, Hang Guo, “Nanopower Betavoltaic Microbattereies,” SonicMEMS Laboratory, School of Electrical and Computer Engineering, Cornell University, Ithaca, NY

[2]Bates J.B., et al., “Rechargeable Solid State Lithium microbatteries,” Proc. MEMS Worksop, 1993, p.82-86

[3]Braun J., Fermvik and Stenback A., “Theory and Performance of a Tritium Battery for the Microwatt range”, J. Phys. E, Vol. 6, P. 727-731, Mar. 1973

[4]Li H., Lal A., Blanchard J., and Henderson D., “Self-reciprocating Radioisotope-Powered Cantilever,” J. Appl. Phys., 92, 2002,1122-87

[5]IEEE Spectrum, September 2004, page 36

[6]M.El-Wakil, Nuclear Energy Conversion, Amer. Nuc. Soc., 1978

[7]New Scientist, vol. 172 issue 2318, November 24, 2001, page 30

[8]Oscar S. Cisneros, “Micro Devices Get Nuked,” Wired News, July 1, 1999

[9]Rappaport P., Loferski J.J, and.Linder E.G, “The Electron-Voltaic Efect in Germanium and Silion p-n junctions,” RCA review,17(1956),100

[10]Schaevitz S.B.,.Franz A.J, Jensen K.F., and Schmidt M.A., “A Combustion-Beased MEMS Thermoelectric Power Generator,” Dig.Tech., Transducers’01, 2001, p.30-3

[11]Science News, August 24, 2002, vol. 162, p. 125

[12]Thomas A., ”Nuclear Batteries: Types and Possible Uses”, Nucleonics, Vol. 13, No. 11, P. 129-133, Nov.1955.

[13]W.Y. Sun, Geun Kim, and S.S. Yang “Fabrication of Micro Power Source (MPS) Using a Micro Direct methanol fuel cell (µDMFC) for the medical application,” Tech. Dig. 14th MEMS, 2001, p.341-4

[14]http://homepages.cae.wisc.edu/~blanchar/res/batteries.htm