SFINKS -SelF-powerIng electroNics – the Key to Sustainable future

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ABSTRACT

In this paper we present the first always-delivering electrical generator (***SFINKS)*** harvesting energy from an omnipresent energy source. This is the first harvester free of any installation constraints, and also the first micro-scale generator using atmospheric ***P***ressure and ***T***emperature ***(P/T)*** "tides" to produce electricity! ***SFINKS*** aims at development of quasi-eternal energy generators that can work unattended, always and everywhere. It sounds like a dream since none of the existing electricity generators is capable of doing so. Photovoltaics produce energy only when exposed to light, thermoelectric generators work only when attached to a heat source, etc. ***SFINKS*** embodies the breakthrough idea to harvest energy from natural ***P***/***T*** variations that are omnipresent. Therefore, ***SFINKS*** realizes the dream idea of "drop and forget " –***SFINKS*** can be literally dropped without any care of positioning or installation. As it is inexhaustible, it can be deployed and forgotten for years, remaining operational. Solar planets and satellites can benefit from ***SFINKS*** generators, as they are subject to very large daily temperature variations.

Keywords: energy harvesting, self-supplying, battery-less electronics, energy generation from variations of temperature and/or pressure, autonomous sensors, internet of things, network of sensors, energy micro-generators

1. INTRODUCTION

Scientific and technological achievements are often accompanied with pollution of the planet. Even electronics, believed clean, produces waste counting in trillions of batteries, see Figure 1.

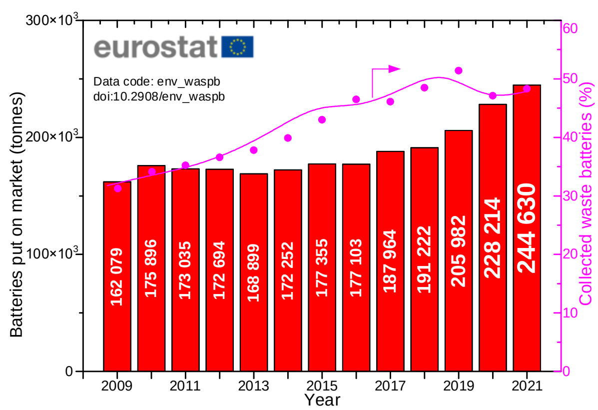

Figure 1 In Europe around 50% of exhausted batteries are recycled, the remaining portion contribute to degradation of the environment[1].

It becomes clear that we need an omnipresent and always delivering energy source along with a harvesting device that would exploit this energy source without any need for installation or positioning. It sounds like a dream since none of the existing electricity generators is capable of doing so. Photovoltaics produce energy only when exposed to light, thermoelectric generators work only when attached to a heat source, etc. The breakthrough observation we have put forward on the ***SFINKS*** project is to realize that not only seas are exhibiting tides, the atmospheric ***P***ressure (***P***) and

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Temperature (***T***) also do something similar [2]. ***SFINKS*** [3] will try to spark a new era of battery-less electronics via exploitation of the natural ***P***/***T*** "tides" to produce electricity in innovative micro-generators. The *magic* of the ***P***/***T*** "tides" resides in that they are always-delivering, periodic and omnipresent, see Figure 2.

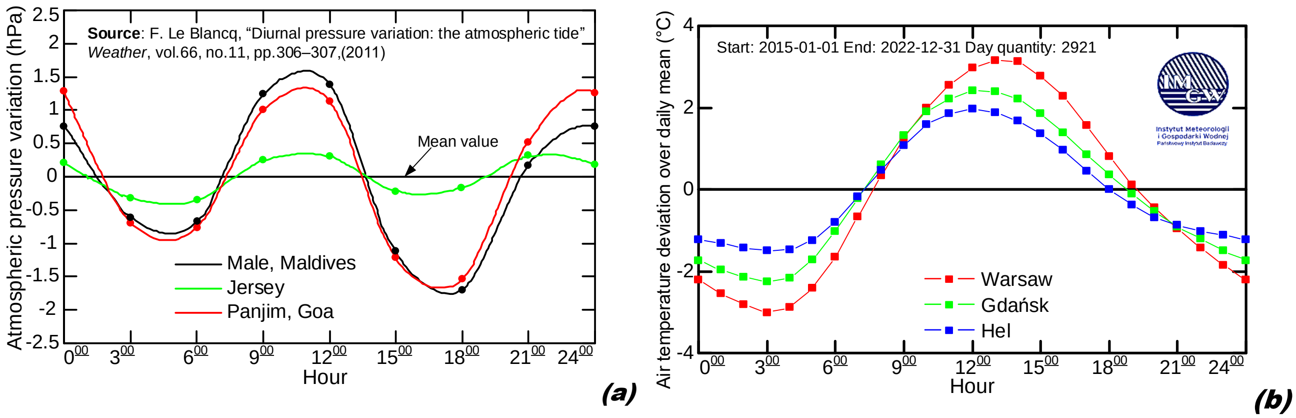


Figure 2 Examples of atmospheric pressure [2] – (a) and temperature – (b) "tides".

SFINKS is using the energy of these ***P***/***T*** "tides" and is the first always-delivering electrical generator harvesting energy from an omnipresent energy source. This is the first harvester free of any installation constraints, and also the first micro-scale generator using atmospheric ***P***/***T*** "tides" to produce electricity! Interestingly, this idea was exploited in the past in clock based on the principle of ***P***/***T*** "tides" in early 17^{th} century constructed by C. Drebbel. One of its followers, the Beverly clock, is still running despite never having been wounded since 1864. However, for all these 400 years the invention has remained relatively bulky and stagnated at mechanical energy stage. The most recent version, named ***ATMOS***, see **Fig. 3,** is still fabricated and commercialized by Jaeger-LeCoultre[4], a Swiss clock maker. In this clock, a variation of temperature by no more than 1°C provides enough energy to power the clock during 4 days. Note that the expansion chamber in the ***ATMOS*** clock is filled with chloroethane rather than with air. This is due to the fact that the boiling temperature of chloroethane is around 7°C, therefore at room temperature the chamber contains saturated vapors of chloroethane. This is essential for the success of the concept, since the pressure variation with temperature around 300K is 10 times larger for saturated vapors than for an ordinary gas.

Figure 3 ***ATMOS*** clock – chloroethane is used due to its X10 larger vapour pressure sensitivity to temperature variation.

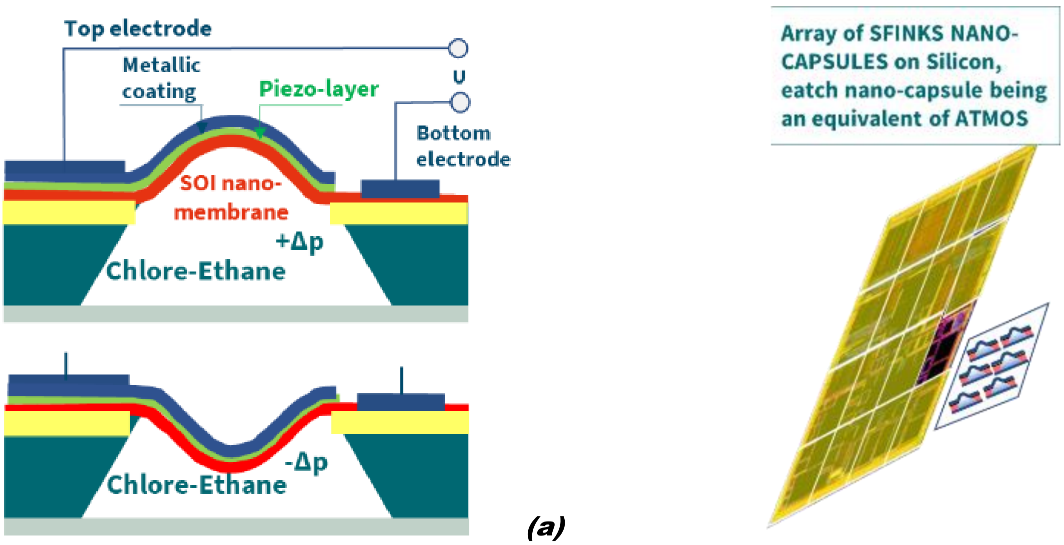
In spite of these wonderful features, having a closer look at the ***ATMOS*** clock – Figure 3 makes one notice many points requiring radical innovations: (***i***) – it is bulky; (***ii***) – it is very costly, its price is around 20k€; (***iii***) – it is manufactured with a craft-like technology; (***iv***) -the generated energy is mechanical, whereas we need electrical energy; (***v***) – the expansion of the chloroethane chamber is too slow a movement to generate electric energy.

2. METHODOLOGY OF IMPROVEMENT

In the ***SFINKS*** project we are developing a technology enabling miniaturization of the ***ATMOS*** clock to the size of a nano-capsule compatible with the monolithic Silicon technology and equip it with an innovative co-integrated conversion to electrical energy. Our methodology is based on four breakthrough ideas:

1. "Scale-down" the ATMOS machinery using a cheap Si-nano technology

The manually manufactured metallic bellow used in ***ATMOS*** is replaced by an array of microchambers etched in a ***S***ilicon ***O***n ***I***nsulator (***SOI***) wafer, see **Fig. 4**. The advantage of such an approach is that the number of chambers has a very limited impact on the process difficulty and cost. We will thus etch a large number of chambers side-by-side.



(a) ***(b)***

Figure 4 The bellow of the ***ATMOS*** clock as replaced by a microchamber etched in an SOI wafer–(a); and (b)–an array of microchambers.

2. Add a mechano-electrical piezo transducer

Upon ***SOI*** wafer a metallic electrodes are patterned using optical lithography and deposited using thermal evaporation. Subsequently, thin-film lead zirconium titanate (***PZT***) piezoelectric is deposited using ***P***ulsed ***L***aser ***D***eposition (***PLD***). Afterwards, top metallic electrodes are lithographically transferred upon the wafer and deposited using thermal evaporation. Finally, the chambers are etched from the bottom side and remain closed at the top with the ***SOI-PZT*** nanometer-thick layers forming elastic membranes that are naturally concave after etching – forming a mechano-electrical transduder. For more details see the paper by M. Filipiak, *et. al.* (doi: 10.1117/12.3058380)[5], this conference.

3. Employ sharp flipping of a bistable nano-membrane to generate strong piezo response

As the pressure inside the chamber increases (*due to an increase of the ambient temperature*) it briskly flips to a convex position. This sharp and dynamic deformation produces an electrical response from the piezo layer covering the membrane.

4. Ultimately, co-integrate with Low Power CMOS to get self-powered nano-electronics

The signals from the piezo-transducer are rectified and their energy stored in a buffer. The latter constitutes an energy storage capable of supplying ***I***nternet ***o***f ***T***hings (***IoT***) nodes and other ***L***ow ***P***ower (***LP***) circuitry.

3. FIRST RESULTS

First of all we have to find out how scaling-down affects the amount of produced energy. Scaling-down is mandatory if we think of harvesters aimed at supplying ***I***ntegrated ***C***ircuits (***IC***). The representative size of modern ***IC***s counts in square centimeters. We have thus performed the following numerical experiment. Using the ***COMSOL*** numerical multi-physics simulator, we have calculated the total electric energy produced within one single membrane switching event for: (***i***)-one single membrane fabricated on 1cm^2 of Silicon; (***ii***)- 4 membranes on 1cm^2; (***iii***)- 16 membranes on 1cm^2; (***iv***)- 64 membranes on 1cm^2; and so on. The results, presented in Figure 5, confirm that scaling-down increases the energy up to a certain point (*in this case 8 membranes on 1cm^2*). Scaling-down beyond this point reduces the amount of produced energy. Additionally, at each data point in the graph, the corresponding membrane thickness (***t***) and the initial depth (***C***) are specified, showing that as the membrane density (number of membranes per cm²) increases, ***C*** and ***t*** are decreasing to maintain the required pressure threshold for flipping. It is important to note that at 20°C, the vapor pressure of chloroethane is approximately 30kPa, which is taken into account in these calculations.

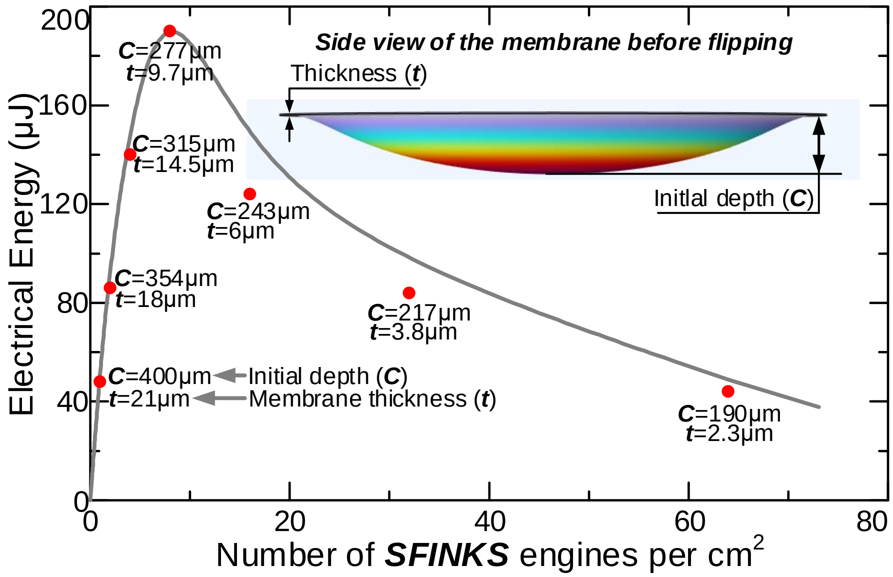
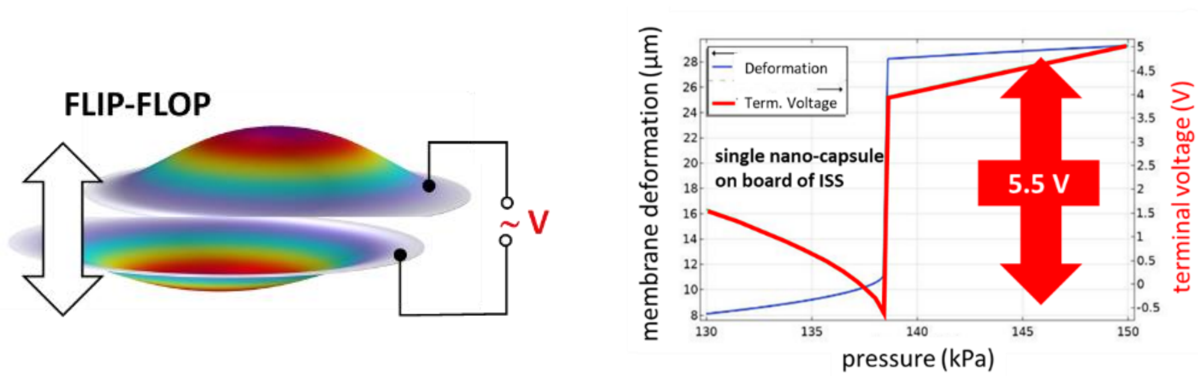


Figure 5 Daily production of electrical energy on Earth (*2 flipping events per day*) as function of the number of ***SFINKS*** engines per cm^2.Data points labels are highlighting membrane depth before flipping (***C***) and thickness (***t***). ***C*** and ***t*** are modified in such a way to maintain similar flipping pressure below 30kPa

The first technological results will be presented in the paper by M. Filipiak, *et.al.* (doi: 10.1117/12.3058380)[5]. Here we will focus on electrical simulations with the use of the ***COMSOL*** software. As shown in Figure 6, a single membrane flipping can produce pretty large voltage pulses, in this particular case 5.5V, which means a lot of energy. Due to the extremely low power consumption of the modern IoT nodes[6–8] , the total energy thus obtained from a 1cm^2 array of ***SFINKS*** generators, can power a few ***IoT*** nodes on Earth, and on Mars (2 flipping events per day), and much more on ***I***nternational ***S***pace ***S***tation (32 flipping events per day). This is a very encouraging result.



(a) ***(b)***

Figure 6 ***COMSOL*** simulation results of the flipping process of a ***SFINKS*** membrane –(a), and its piezo response – (b).

4. SUMMARY

Thanks to the ***E***uropean ***R***esearch ***C***ouncil (***ERC***) advanced grant we have woken up a concept remaining in stand-by for 400 years. We have scaled it down by many orders of magnitude to the form of a nano-capsule. The nano-capsules are arranged into arrays and fabricated using modern Silicon ***M***icro ***E***lectronic ***M***echanical ***S***ystems (***MEMS***) technology. We have also equipped the nano-capsules with a piezo transducer thus permitting production of electrical energy instead of mechanical energy. We have proven that scaling down increases the total energy achievable from a unit area. The resulting ***SFINKS*** harvesters can power ***LP*** electronics on Earth, on satellites as well as on solar planets, e.g. on Mars. The beauty of the concept resides in that it is the first kind of "*drop and forget* " harvester that does not require any installation, maintenance or positioning, and is quasi eternal. This beauty is schematically illustrated in Figure 7.

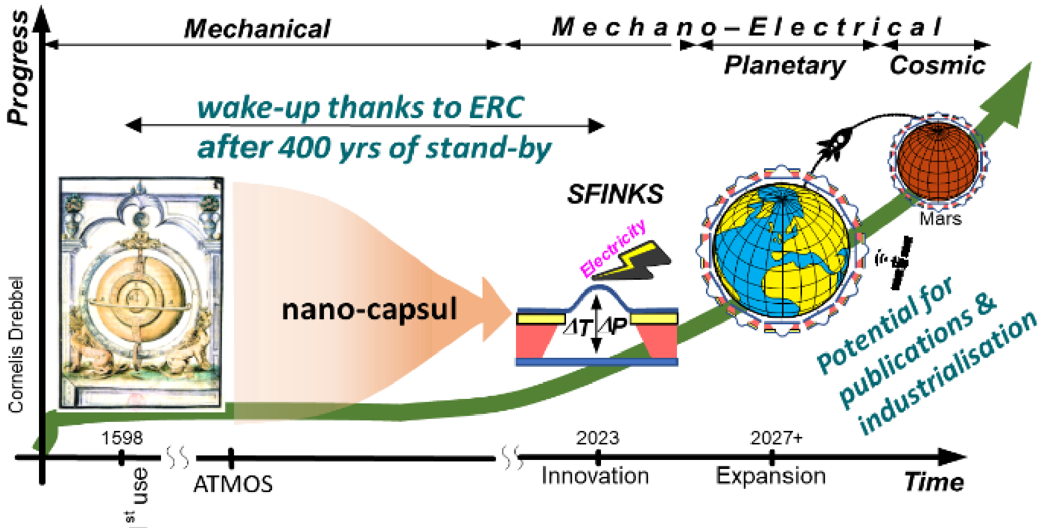


Figure 7 Origin and prospects for ***SFINKS***

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