Study of an off-grid wireless sensors with Li-Ion battery and Giant Magnetostrisctive Material

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Realization of an off-grid wireless sensor through vibrational magnetostrictive energy harvesting

Thesis Abstract

Recent technological advances in Micro Electro Mechanical Systems, wireless communications and digital electronics have allowed the development of cheap, multifunctional and low-power appliances able to communicate each other by means of wireless technology with a limited distance range. These small devices, called sensor knots or motes, are made up of components able to detect physical quantities (position, temperature, humidity, etc.), to process data and to communicate each other. Figure 1 shows the Bluetooth Low Energy (BLE) temperature and humidity sensor considered in this thesis work having a radius of 15 mm.

Figure 1: The BLE-sensor (15 mm radius) is able to communicate via Bluetooth with the receiver, generally a smartphone. It gives information of temperature and humidity and is supplied by a CR2032 coin battery. Image taken from: https://www.global-tag.com

When the power grid is not available, a power supply is needed to make these systems autonomous. Commercial batteries can be a quick and easy solution but require at least an annual maintenance. The resultant periodic replacement makes such systems less autonomous and the maintenance is a cost and sometimes a problem. To overcome this limit, it is necessary to find elsewhere an energy source capable to supply the sensor continuously for a longer period. Energy Harvesters (EHs) respond perfectly to this need since they do not need human intervention, having a lifespan of 10 or 20 years and being environmentally friendly.

This thesis work focuses on the development of a magnetostrictive vibrational EH, coupled with a supercapacitor or a newly developed Lithium-Ion (Li-Ion) rechargeable battery, fitted with improved electrodes. Vibrational EH has the advantage of exploiting one of the energies available for harvesting with the highest specific power. This work explores the design parameters of a direct-force magnetostrictive vibrational EH, through a dual experimental and modeling approach. At the same time, the study focuses on the creation of an experimental Li-Ion rechargeable battery. The latter is improved through the analysis, preparation and construction processes of the electrodes

and in particular of the anode. Finally, the study is completed with the design and construction of a signal conditioning circuit for the recharging of the storage element. The assembly of the whole system and the coupling with the BLE sensor led to a very promising final experiment.

The aim of this research, as already explained, is twofold.

On one side, the activity is devoted to the development of a fully characterized Fe-Ga rod vibrational energy harvester. The goal of this study is to fully understand the interactions and respective influences on the overall performance of several parameters (such as mechanical and magnetic bias, stress applied and load resistance) in order to evaluate the best working condition for a given energy source and then increase it through the design of a properly mechanical yoke for the Fe-Ga rod. The results can be summarized with the curves family shown in Figure 2.

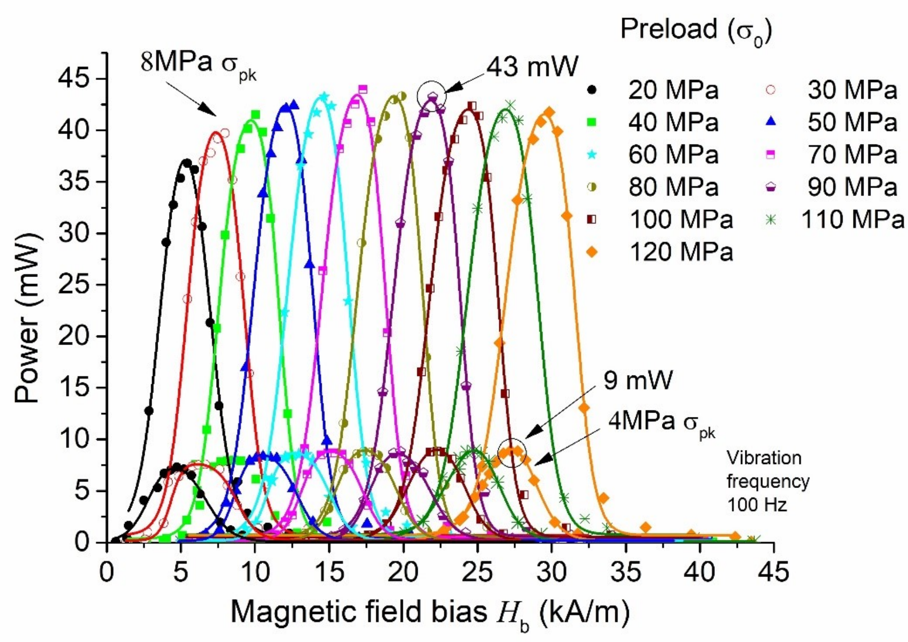
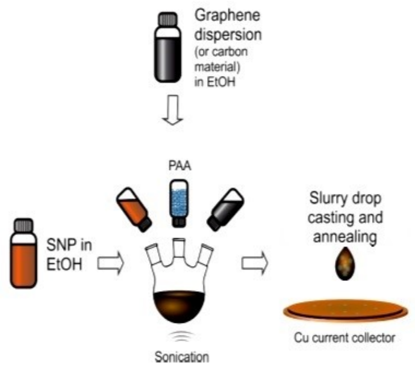


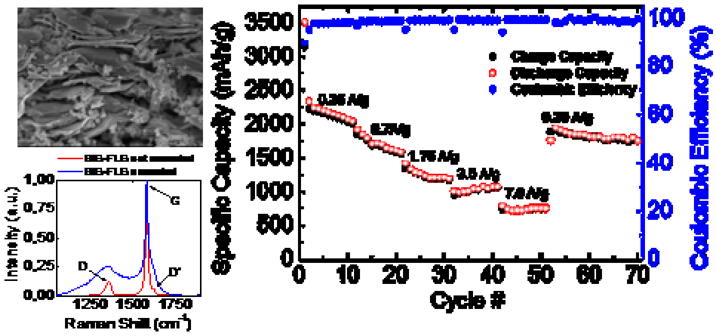
Figure 2: A complete study of the combined effect on the output performances of the magnetic bias and of the mechanical preload. Image taken from [1]

The diagram demonstrates that, for each mechanical preload, it exists a value of the magnetic bias which can maximize the output power of the harvester or, backward, for each value of magnetic bias, there is a mechanical preload capable to maximize the output power. The figure proves that lower values of magnetic bias can generate high output power, comparable with the ones obtained with higher magnetic bias. This shows that the use of permanent magnets, which generally provide a limited bias, does not affect the performances of the device, removing a possible constraint in the harvester design.

On the other side, great efforts are devoted to the analysis of the interaction between graphene and silicon as anode materials for the design and realization of new and improved Li-Ion batteries (LIBs). The goal is to obtain a long life, high-rate and high-capacity LIB through a scalable, low cost and low time-consuming process. The process, shown in Figure 3a, involves the realization of a sonicated composite in ethanol and subsequently subjected to annealing. An HR-SEM image of the composite after the annealing process is presented in Figure 3b, together with a Raman spectrum. The latter indicates the realization, after the annealing process, of graphitic carbon ascribable to the realization of a carbon coating over the Silicon nanoparticles.



(a)



(b)

Figure 3: (a) scheme of realization process for the Si-FLG nanocomposite; (b) graphic summary of the main features of the new anode material. Image taken from [2]

The rate capability of Figure 3b demonstrates that the new anode material possesses high stability and is be able to work also at high current (7.0 A/g). Moreover, increasing the mass load, the anode material shows these behaviours both as a thin film and as a bulk material, reaching and overcoming a real capacity of the highest performing cathode on the market (2.5 mAh/cm^2). Due to these performances, the anode can be subsequently used in a Li-Ion cell together with a commercial cathode (NMC 111).

At the end, a complete EH device with a Bluetooth Low Energy (BLE) sensor is assembled and verified in laboratory to test the results obtained mimicking a real application. It has been demonstrated that in a real scenario, where the harvester is coupled to a continuous source, for instance to a device like a machine tool here simulated by a dynamic test machine, the system can work with a supercapacitor for more than 10 hours when source stops, covering a workshift. With the rechargeable battery the working time span of the BLE can reach the same range, but up to now, the capacity of the experimental battery is limited to one percent of a commercial 2032 battery.

The activity has been carried on among three locations: IIT Labs in Genova, Politecnico di Torino Labs and INRiM Labs in Torino.

REFERENCES:

[1] S. Palumbo, P. Rasilo and M. Zucca, Experimental investigation on a Fe-Ga close yoke vibrational harvester by matching magnetic and mechanical biases, *Journal of Magnetism and Magnetic Materials*, 469, 2019, 354-363, https://doi.org/10.1016/j.jmmm.2018.08.085.

[2] S. Palumbo, L. Silvestri, A. Ansaldo, R. Brescia, F. Bonaccorso, and V. Pellegrini, Silicon Few-Layer Graphene Nanocomposite as High-Capacity and High-Rate Anode in Lithium-Ion Batteries, *ACS Applied Energy Materials*, 2(3), 2019, 1793-1802, https://doi.org/10.1021/acsaem.8b01927.