Marie Curie IEF, Project No: 330547
High Performance Energy Harvesters (HiPER)
Project Summary

Micro-electro-mechanical-systems (MEMS) impact everyone every day. Mobile phones, watches, automotive, train and plane safety systems, sports tracking devices and medical implants such as hearing aids, pacemakers and drug delivery devices are only a few examples of portable goods that include MEMS technology. Such products mostly rely on batteries as their source of power. Regrettably, the battery life of these devices is limited resulting in maintenance costs, environmental concerns, and in some cases even risk to life. Harvesting energy from everyday motion, otherwise left unused, is a recent approach to supply energy for low power electronics, ranking as one of the current top 10 technologies according to EE Times. Nevertheless, the performance of energy harvesters up to now has not been sufficient, particularly for body-worn applications where the motion tends to be slow and irregular. For small devices based on MEMS technology, this problem becomes an even greater challenge as reaching low natural frequency is impossible without compromising other essential features due to scaling effects.

The primary aim of this project was to develop novel designs of miniature energy harvester that are able to work at low frequencies. The key idea was to use novel spring suspensions with tailored elastic properties, designed using the force composition method. By combining non-linear and linear compliant mechanisms, a suspension can be made to exhibit near-zero stiffness in one axis while remaining stiff in the other axes. This allows the operating frequency of a harvester to be reduced substantially. Alternatively, particular forms of non-linear behaviour, such as bi-stability, can be built in. This is an entirely new approach to energy harvester design that opens up possibilities for harvesting effectively at low frequencies and over wider frequency ranges. Being a straightforward method, the approach is not only a key enabler for wearable MEMS devices, but will also serve as a framework to guide other industrial applications.

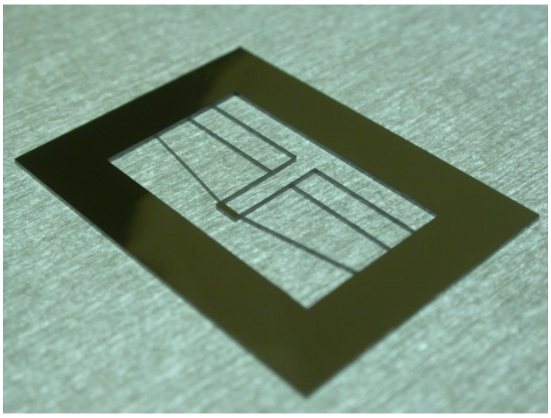
The Marie Curie Fellow had previously worked in the area of compliant mechanisms but had no previous experience of MEMS technology or energy harvester design. A significant amount of technical training was therefore required, both in microfabrication and the theory of energy harvesting. The necessary testing facilities also had to be established. The research activities proper started with the design and fabrication of a linear energy harvester to serve as a benchmark and a starting point for subsequent work on nonlinear energy harvesters. A cantilever beam with a bonded polymer piezoelectric film was used as the linear energy harvester. By attaching magnets, nonlinearities were induced in order to investigate the principle of non-linear harvesting at the early stage of research.

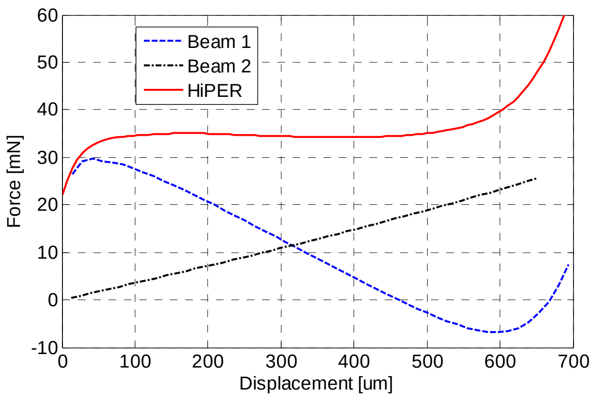
In parallel with the above activities, a survey of existing energy harvester designs was carried out with a view to re-classifying them in compliant mechanism terms as function, function-motion or function-path generators. The aim was to understand the full range of designs in the literature and look for opportunities for design improvements. A study was also made of the trade-offs involved when deciding between designs with single or multiple degrees of freedom. The trade-offs associated with different designs were estimated by analysis and the results were verified through numerical modelling.

During the early stages of the project it became clear that a facility for rapid prototyping of silicon suspensions would be of great value. Therefore, significant effort was devoted to establishing a process for laser micromachining of silicon structures, using UV laser facilities in the host research group. This made possible the rapid fabrication of silicon beams with aspect ratios similar to those achievable with traditional MEMS fabrication. Moreover, the same process could be used for trimming devices to compensate for dimensional errors arising during fabrication. The processes developed in the course of this work are not only relevant to micro-energy harvesting, but should also be of interest to the wider MEMS community.

Using the force composition method, a number of silicon suspensions suitable for use in low-frequency energy harvesting were designed. The expected performance of these structures was verified by finite element analysis. Prototype devices were fabricated in the host laboratories, both by tradition microfabrication based on deep reactive ion etching, and also by laser micromachining.

Overall this research project has opened up an entirely new way to design micro energy harvesters for low frequencies, ultimately enabling low power portable electrics to run for the lifetime of the device, impacting everyone, every day.





LEFT: Near-zero-stiffness suspension fabricated in silicon by deep reactive ion etching.
RIGHT: FEA (finite element analysis) results showing force-displacement curves for constituent linear and non-linear elements, together with overall characteristic showing near-zero differential stiffness in central region.

The project was hosted by the Optical and Semiconductor Devices Group, Department of Electrical and Electronic Engineering, Imperial College London. The project duration was 15 months.