A Portable Power Source Based on MEMS and Carbon Nanotubes

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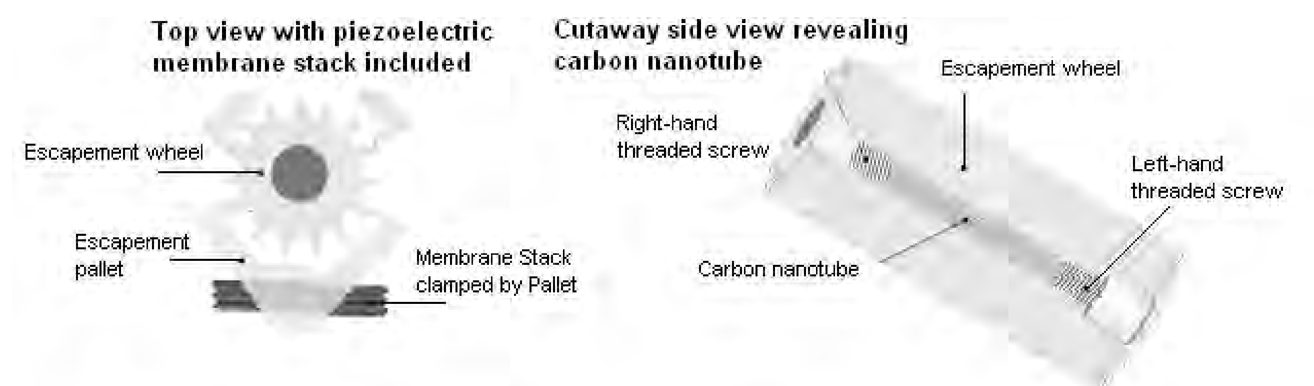
There is a growing need for small, lightweight, reliable, highly efficient and fully rechargeable portable power sources. The focus of this project is the design and modeling of a system in which energy is stored in the elastic deformation of carbon nanotube (CNT)-based springs. The CNTs are coupled to a MEMS electric generator. When the CNT deformation is released, the stored energy actuates the generator, which then converts the energy into electricity. The MEMS generator may be operated in reverse, as a motor, in order to wind the CNT springs and recharge the system. Alternatively, the stored elastic energy may be used to supply a mechanical load directly. This project is motivated by recent research into the mechanical properties of CNTs. The CNTs have a high stiffness, low defect density, and a consequently high yield strain that enables them to store elastic energy with significantly greater energy density than typical spring materials such as high-carbon steel. Models suggest that CNTs can be reversibly stretched by up to 15% [1]; lower strains of up to 6% have been demonstrated experimentally to date [2-3].

This type of system offers several important potential advantages. First, due to CNTs' high strength, high flexibility, and low defect density, they can store energy at very high energy density. Considering just the CNT-based spring itself, the energy density of an array of CNTs stretched to a reversible 15% strain is about 1500 W-hr/kg, about ten times the energy density of Li-ion batteries. The energy density of the final system will be lower because of the finite conversion efficiency of the generator and the weight of both the supporting structure and the generator hardware. In addition, because energy storage in the CNT system is based on stretching chemical bonds rather than breaking and reforming chemical bonds as in batteries, the CNT-MEMS generator system has the potential to operate at higher power densities, under harsher conditions, to deeper discharge levels, and through a greater number of charge-discharge cycles than a chemical battery.

The system architecture consists of a CNT-based energy storage element, an energy release rate mechanism, and a MEMS generator. This project is examining and modeling different variations on this system architecture that incorporate different modes of deformation of the CNT-based energy storage element, various types of generators, different types of coupling between the storage element and the generator, and different size scales for the various components. One conceptual example is illustrated below, in which the axial relaxation of an axially-stretched CNT-based storage element is converted to rotational motion of a wheel. The wheel is coupled to a piezoelectric generator through a mechanism that regulates the rate of energy release, much as in a mechanical watch.



▲ Figure 1: Schematic diagram showing the conceptual design of a MEMS-based energy storage device

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