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Triboelectric motion sensor combined with electromagnetic induction energy harvester

L.E. Helseth*, X.D. Guo

Department of Physics and Technology, Allegaten 55, 5020 Bergen, University of Bergen, Norway

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ABSTRACT

We investigate the possibility of combining electromagnetic induction and triboelectricity for creating a low-friction floating magnet-based sensor system to detect motion and harvest energy from small vibrations or oscillatory magnetic fields. We designed a system with low friction such that the energy harvester based on electromagnetic induction is not influenced by the triboelectric transduction mechanism. An enclosed system combining a triboelectric and electromagnetic mechanism which responds to vibrations or changes in magnetic fields was designed. The system comprises an aluminum-covered magnet placed inside a tube covered by metallized fluorinated ethylene propylene. The sliding action between the metal and the polymer causes triboelectric charging. The magnet acts as a carrier for the aluminum surface, but is also used to induce a voltage in a copper coil, thus allowing one to detect the same mechanical motion utilizing two different technological principles. The main advantage of our design is an enhanced sensing mechanism based on the triboelectrical signal that does not require one to interpret the complicated electromagnetically induced signal that may occur for complex magnet geometries.

1. Introduction

Small-scale sensor and energy harvesting systems are becoming more and more important as sensor technology is downscaled in size and power demand. Autonomous sensor systems, driven by power sources that harvest all their energy from the environment, are often considered a key factor for the technology drive. Early efforts focused on small-scale electromagnetic harvesters [1], and this field has now grown into a well-developed research field [2–6], from which practical systems continue to emerge. Recent developments include on electromagnetic motion and harvesting systems for detecting and harvesting energy from human motion [7], structural vibrations [8], fire monitoring [9]. Ref. [10] gives a good overview over recent efforts on utilizing electromagnetic and piezoelectric mechanisms for energy harvesting purposes.

As electromagnetic harvesting systems rely on motion to induce an electrical potential difference, mechanical amplification of the motion is sometimes needed [11]. Moreover, efficient coupling of electromagnetic and mechanical degrees of freedom is required, which has resulted in different designs with the aim of guiding the magnetic fields [3,5,7,12]. The coupling between different operational modes, e.g. electromagnetic and piezoelectric, is particularly interesting, as they may complement or enhance the performance of the harvesting or detection system [13–15]. To this end, an emerging field of energy harvesting is that of triboelectric generators based on micro and nanostructured polymers [16,17]. The complementarity between electromagnetic and triboelectric generators has been investigated [18,19], and combined harvesting systems have been demonstrated [19,20]. While small-scale electromagnetic generators usually produce large currents and small voltages, triboelectric sensors may generate small currents and large voltages, and they may therefore complement each other if both characteristics are needed. Moreover, these two principles may allow one to detect motion in two different ways. Here we investigate the possibility of creating a floating magnet-based sensor system to detect motion and harvest energy from small vibrations or oscillatory magnetic fields. As a design constraint, it is crucial that the system exhibits low friction and that the two modes of electrical signal generation gives distinctly recognized patterns.

2. Experimental methods

Fluorinated ethylene propylene (FEP) film of thickness 25 μm (DuPont) was nanostructured using Reactive Ion Etching (RIE). The reason for nanostructuring the polymer surface is twofold: Increased surface charge when applying RIE etching and nanos-

* Corresponding author.
E-mail address: Lars.Helseth@ift.uib.no (L.E. Helseth).

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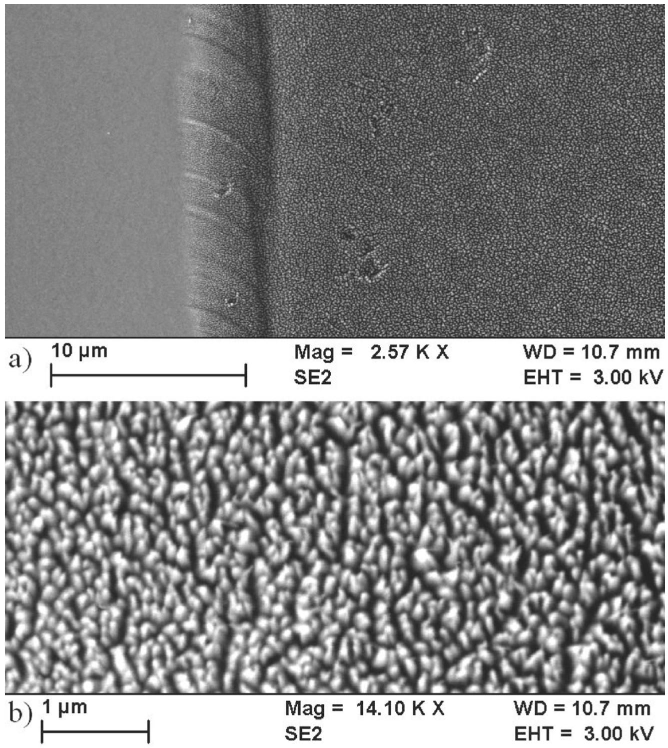

Fig. 1. Scanning electron microscope image (Raith) of the polymer after reactive ion etching. The left part in (a) shows the untreated part, whereas the right part shows the treated part. (b) Shows a close-up of the etched part.

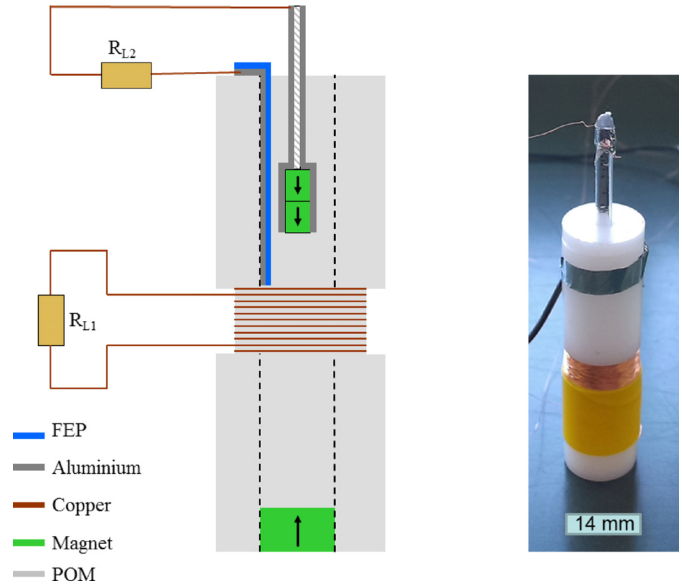

Fig. 2. Schematic drawing of the harvesters (left) and a photograph (right).

tructures that provide a smoother surface [21]. The film was first cleaned with isopropyl alcohol and deionized water, then blown dry with nitrogen gas. In the etching process, O_2 and He gases were injected into the chamber with flow ratios of 5 and 10 standard cubic centimeters per minute, respectively. Plasma was accelerated by a power of 150 W, and the total etching time was 20 min. After the RIE, the side of the polymer not exposed was covered by a 70 nm layer of aluminum using Electronbeam Evaporator (Temescal FC-2000). The RIE treatment induced nanostructures were inspected by a Raith field emission scanning electron microscope operated at 3 kV, as shown in Fig. 1.

On the left in Fig. 1(a) untreated polymer is shown, whereas the right hand side shows etched polymer. A close-up of the etched part reveals nanostructures as seen in Fig. 1(b). A rough estimate of the size of these nanostructures gave (76 ± 25) nm, with a length of the order of 100 nm. A more detailed characterization of the nanostructured FEP and its contact electrification with aluminum can be found in our previously published report [21].

After nanostructuring the FEP film, a system combining electromagnetic and triboelectric harvesters was assembled, as shown schematically in Fig. 2. The picture on the right is a photograph of the actual system. In order to implement a combined system, one has to decide whether to use a mechanical stop, a mechanical spring or a floating magnet system. The analysis of free motion versus impact reveals different kinetic modes which must be considered when designing harvesting systems [22,23]. Alternatively, floating magnet systems can also be utilized [7]. Here we employed a hybrid system with a floating magnet system on one side and an end-stop for preventing extreme amplitudes, since the goal was to design a system which minimizes mechanical impact and reduces the needed mechanical components.

The body on which the harvesters were mounted was made in white PolyOxyMethylene (POM) with a hole of 5 mm diameter going through the body. A 5 mm diameter NdB magnet was glued to the inner walls of the POM near the bottom as seen in Fig. 2. Two NdB magnets of diameter 4 mm and height 2 mm were glued to a 2.7 mm diameter plastic rod. The application of two aligned magnets served two different purposes. First, it allowed us to precisely locate the passage of the magnet system, since the induced potential difference in the coil will exhibit four peaks (as opposed to the two peaks seen for a single magnet). Second, they improved the stability of the magnet system and thus were found to have reduced friction as compared to a single magnet. Finally, as pointed out in Ref. [7], the induced voltage was larger than for a single magnet. The disadvantage is larger mass, but that did not constitute a problem in the current application. The polarity of the magnets was set to ensure that they were repelled from the 5 mm magnet, thus exhibiting damped oscillations when mechanically excited. In addition, we also needed a sufficient large contact area in order to allow triboelectric current generation. The magnets were completely covered by 0.1 mm thick aluminum tape. A wire was connected to the aluminum and a load resistor R_{L2}. A 2 mm wide and about 20 mm long strip of nanostructured FEP with aluminum on the back side was glued to the inner wall of the POM body. When the magnets attached to the polymer rod were moved by mechanical excitations, the aluminum surface would rub against the nanostructured FEP, thereby generating a current. Since the two stacked magnets had a total height of 4 mm, it is clear that at any time at most $4\,mm \times 2\,mm = 0.08\,cm^2$ of the aluminum surface could be in contact with the FEP. Since the inner surface of the POM body had a diameter slightly larger than the aluminum-covered magnets, the effective contact area might be smaller than that expected for a planar geometry, but that will not be considered here.

A 5 mm wide notch in the POM body was used to attach the electromagnetic harvester. This harvester consisted of 900 turns of copper wire of diameter 0.1 mm. The resistance of the copper coil was measured to be 63 Ω. The copper coil was connected to a load resistance R_{L1}. The entire POM body measured 9 mm × 52 mm, with the aluminum-covered plastic rod reaching a maximum distance of 40 mm above the end-cap. Thus, at least 40 mm above the end-cap had to be free for the plastic rod to move freely up and down.

The current and voltage were measured using a Keithley 6514 electrometer, by either connecting the electrometer in series with or in parallel with the resistor in Fig. 2.