

Energy harvester using contact-electrification of magnetic fluid droplets under oscillating magnetic field

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Abstract. This paper reports a fluidic-based energy harvester generating electric power through contact-electrification of ferrofluid droplets, which will allow the power generation using oscillating magnetic field without vibration of any mechanical structure such as membrane or cantilever. The proposed device consists of top and bottom plates with a conducting electrode coated with a hydrophobic layer and water-based ferrofluid droplet. The contact area between the ferrofluid and the solid surface is changed according to the magnetic field applied by a magnet, which generates AC output power by contact electrification at the ferrofluid–solid interface.

1. Introduction

When the surface of a solid material makes contact with an aqueous solution such as water, an electrical double layer (EDL) is formed at the interface by the interaction of surface charges and their counter ions in aqueous solution [1-3]. Recently, a number of research results regarding electric energy harvesting by using the EDL mechanism has been reported. Lin et al. presented energy harvesting devices based on contact electrification between water and a hydrophobic polytetrafluoroethylene (PTFE) surface and the corresponding EDL formation at the interface [4, 5]. In addition, it has been demonstrated that electric energy can be harvested by mechanical modulation of the EDL capacitors formed by the contact of water with the conducting plates [6, 7]. However, those studies used droplets falling on a substrate from some height or mechanical vibration of the substrate itself to create continuous dynamic contact conditions, which hinder the packaging of the devices by limiting their application to a restricted area.

In this paper, we propose and demonstrate an energy harvester using ferrofluid droplets that are deformed by an external magnetic field and consequently provide a dynamically changing contact area at the interface, resulting in continuous charge flow by contact electrification.

2. Proposed device and operational principle

Ferrofluids are categorized as oil-based and water-based fluids according to the base media composing them. When a water-based ferrofluid is in contact with a solid surface, an EDL is formed at the interface. Figure 1 shows the power generation mechanism of the proposed energy harvester using a ferrofluid and the oscillating external magnetic field. The device consists of top and bottom plates with a conducting electrode covered by a hydrophobic layer and water-based ferrofluid droplet. The ferrofluid droplet is dispensed by a pipette. The ferrofluid droplet in this experiment is positively charged while separating from dispenser [8]. So, the electrode surface becomes negatively charged to maintain the balance of the electrical potential. In the initial state, no current flows because there is no potential difference between the top and bottom electrodes, as shown in figure 1(a). When the magnet moves close to the bottom plate, the ferrofluid is pulled downward, and finally separated from the top



plate, as shown in figure 1(b) and figure 1(c). During this operation, the contact area with the ferrofluid decreases on the top plate and increases on the bottom plate. As a result, electrons move from the top electrode to the bottom electrode through the load resistance until electrical equilibrium is achieved. In figure 1(d), the ferrofluid returns to its initial shape to maintain the balance of surface tension on the hydrophobic bottom surface and makes contact with the top plate when the magnetic field applied to the ferrofluid decreases as the magnet moves away from the bottom plate. During this step, the positive charges on the ferrofluid draw the electrons from the bottom electrode to the top electrode, reversing the direction of current flow. Continuous output power can be generated by the reciprocal oscillating motion of the external magnet.

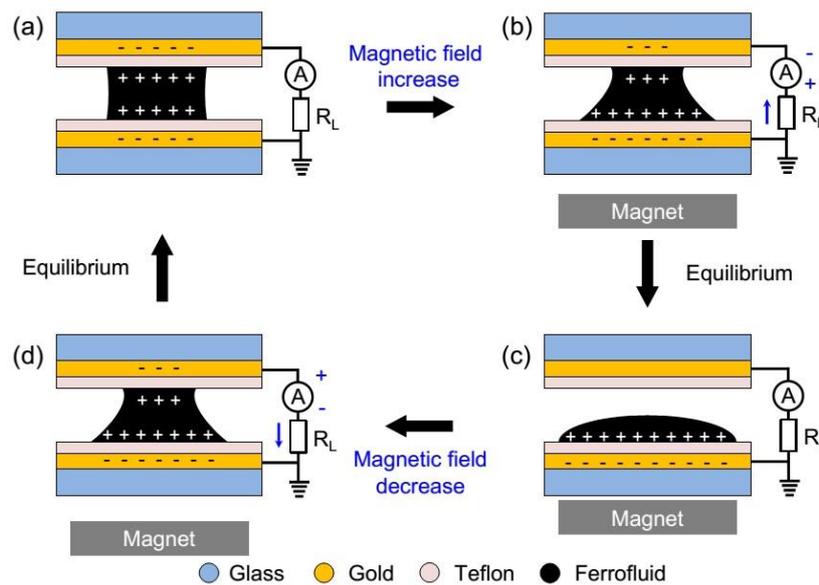


Figure 1. Power generation mechanism of the proposed energy harvester.

3. Fabricated device and experimental setup

In this experiment, we used gold as electrode material as shown in figure 2. The top and bottom electrodes were coated with Teflon (AF 1600) to provide hydrophobic surfaces and prevent stiction of the ferrofluid during operation. A ferrofluid droplet was placed between the two plates. The gap distance between the top and bottom plates was determined by acrylic spacers. The fabricated energy harvester was mounted on a z-axis stage. A cylindrical neodymium magnet with diameter was fixed on a computer-controlled linear actuator and placed under the device.

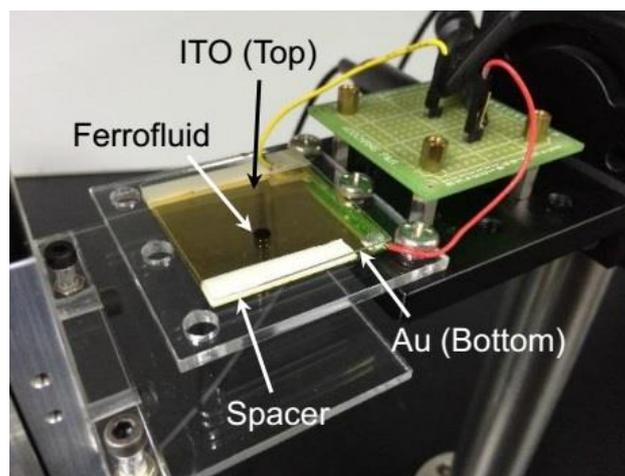


Figure 2. Photograph of the proposed energy harvester.

4. Experimental results

Figure 3 shows the profile of the open-circuit output voltage from the device with a 1.8-mm gap between the top and bottom plates. Positive and negative output signals were observed as the magnet moved up and down. Furthermore, it is clearly shown that the magnitude of the output voltage increases with the actuation frequency because it is determined by the change in the charge flow with time.

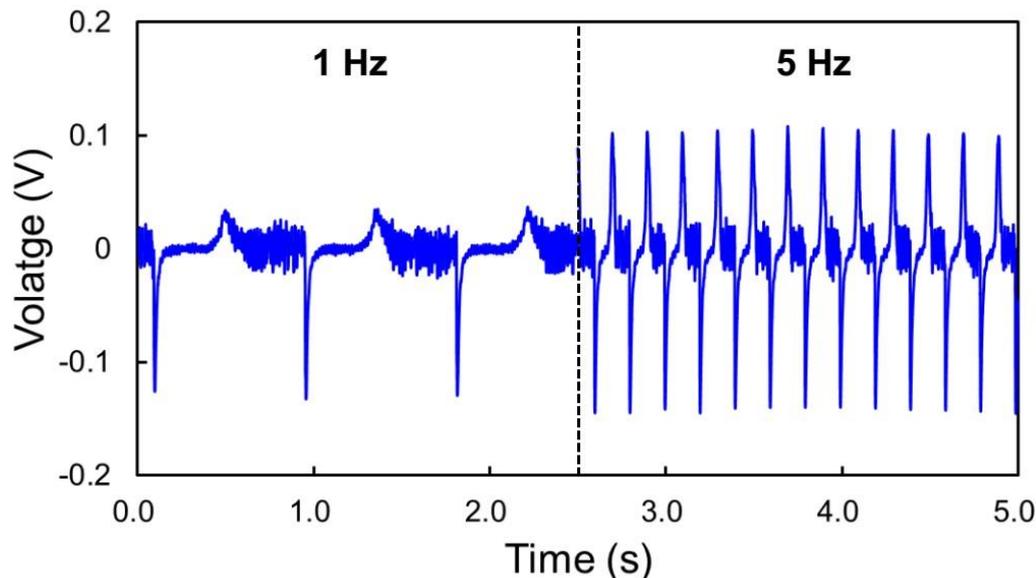


Figure 3. Typical profile of the output voltage at oscillation frequencies of 1 and 5 Hz.

5. Conclusions

In conclusion, we have proposed an energy harvester using contact electrification with a water-based ferrofluid operated by an oscillating magnetic field. The modulation in the contact area between the ferrofluid and the electrodes and resultant power generation were successfully demonstrated. One important advantage of the proposed device is that it eliminates the need to vibrate the device itself to actuate the ferrofluid droplet and to harvest electric power because the shape of the ferrofluid inside the device can be modulated by using an external magnetic field.

References

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