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Fluorinated ethylene propylene thin film for water droplet energy harvesting

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ABSTRACT

We investigate water droplet energy harvesting using transparent hydrophobic polymers. The hydrophobic polymer acts as protection while at the same time harvest energy from the impacting water droplets. The electrodes are mounted at the edges of a transparent window. Such a scheme has the advantage that it allows easy integration with existing technologies and avoids the extra costs and reduced transmittance upon incorporation of partially transparent oxide electrodes covering the entire polymer. Since the electrodes are mounted at the edges of the hydrophobic polymer, the transmittance through the transparent portion is very high, here shown to be >94% for visible light when using thin films of fluorinated ethylene propylene (FEP). It is demonstrated that the system can be mounted on a commercial solar cell for harvesting electrical power from the impact of water droplets, generating an average power of up to 10 mW per square meter of electrode area.

1. Introduction

Traditional harvesting of electrical energy from water involves large, elevated magazines such that the mere height of the water fall provides enough kinetic energy to run the electromagnetic turbines. Such large-scale facilities are important for many countries, but not possible to mount everywhere due to natural conditions. In recent years one has seen a larger focus on alternative water energy harvesting, wherein local facilities based on water waves [1,2] or atmospheric variations [3]. Power plants based on these technologies are usually designed for large-scale supplies (>1 kW) associated with multiple household and entire cities. With the growth of electronic devices requiring small amount of power for operation, the need for local, small-scale energy harvesting has grown [4–6].

Small scale harvesting of energy of from water drops can be undertaken in different manners. In Ref. [7] the deformation of a liquid droplet exposed to acoustic waves was used to drive a piezoelectric cantilever. In Ref. [8], a piezoelectric film was used to investigate the conversion of the kinetic energy of the rain drops into electrical energy. Further studies of piezoelectric energy harvesting have revealed the details of the impact process [9–13] and demonstrated their application in real rain [14].

While piezoelectric materials allow conversion of mechanical energy into electrical energy, harvesting based on contact electrification relies on the development of charges on the polymer surface when water droplets impinge. Although electrification due to water droplets has been investigated for decades [15–18], potential practical applications within energy harvesting have just been developed recently [19–23].

One of the significant advantages of some hydrophobic polymers is that they allow visible light to be passed through without significantly reducing the intensity. These polymers can be mounted on windows or large scale structures for protection, and are often very robust. Fluorinated Ethylene Propylene (FEP) is a common fluoropolymer of relatively low cost and ease of mass production. While there are cheaper and more transparent polymers available on the market, the use of polymers for harvesting electrical energy from impinging water droplets must mainly consider the fact that as much electrical surface charge as possible should be generated when the polymer is contacted by water. With its very high density of fluorine atoms, FEP is therefore a natural choice. Other fluoropolymers with lower density of fluorine atoms could also be considered. However, unlike e.g. Teflon, FEP is also melt-processible, thus adding possibility for processing suitable structures. Such transparent polymers may provide a useful method to protect and harvest energy even in very dark and rainy winter months. Considerable research has been dedicated to the design of

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smart windows, which should be able to protect its interior, control the light spectrum and harvest or store energy (see Ref. [24] and references therein). The proposed fluoropolymer thin film may add functionality to the smart window, in that energy harvesting can be done as long as rain droplets hit the window.

The comparison between different types of energy harvesting systems is important, and such studies have been done for radio frequency and solar cell harvesters [25]. Clearly, commercial solar cells are expected to perform better than the proposed rain energy harvester when sufficient light is available. Although difficult, there is no physical reason why the transferable charge density and the contact area changing rate cannot be increased by chemical and structural modification of the fluoropolymer, at least up to the magnitude where the charge density results in dielectric breakdown. Nonetheless, despite the relatively low power density, the ease of mounting of the proposed geometry on existing commercial systems and the additional protection offered by the polymer films provide attractive features which should allow such a system to be of interest for low power applications on structures requiring protection from thin film hydrophobic polymers.

2. Energy conversion mechanism

A schematic diagram of the system is shown on the left in Fig. 1, where a resistor of variable load resistance R_L is connected in series with an amperemeter to measure the current generated by the water droplets. In this conceptual picture the electrode is placed around the window in a u-shape to maximize the area and make sure that droplets impinging from several directions could contribute to the current generation. However, depending on the practical needs or available space for the electrodes, they can also be placed as a strip at the lower edge (if the droplets are pulled down the polymer slope and over the electrode by gravity) or in an L-shape (if the wind blows the droplets in one direction and gravity pull them downwards). The main point here is that the electrodes are mounted at the edge of the window where they do not obscure transmission of light, while at the same time not missing any droplets escaping the polymer surface. In this study, we consistently used 0.1 mm thick aluminum tape as electrodes. The electrodes were glued to the outer edges of the structure of interest, which could either be a window surface or the transparent epoxy cover layer of a commercial solar cell. Next, the FEP thin film was glued to the metal electrode. Care was taken to cover the metal electrodes and the underlying substrate to avoid unwanted water contact. The system was aligned at an angle of 45° with respect to the vertical line the water droplets were following.

A simplified schematic diagram showing the charge transfer processes is given in Fig. 1 a)–f). We imagine first an uncharged water droplet directly above the polymer film as shown in Fig. 1a). When the droplet impacts the hydrophobic polymer, an electrical double layer emerges at the polymer-water interface, see Fig. 1b). The charge induced at the electrodes when the droplets roll over its edge initiates a current peak (Fig. 1c), whereas no current is observed when the droplet is not near an electrode (Fig. 1d). A current peak of opposite polarity is observed when the droplet passes the lower edge of the electrode (Fig. 1e). Finally, far from the electrode edge, no further charge is induced from that particular droplet (Fig. 1f). It should be noted that the two current peaks may not be equal, since the rolling over and rolling past the electrode may not exhibit the same mechanical dynamics, but the integrated charge from each peak should be of equal magnitude and opposite sign in absence of charge build-up or decay. It should also be pointed out that Fig. 1 for clarity only depicts the charge associated with the newly formed electrical double layer, such that e.g.

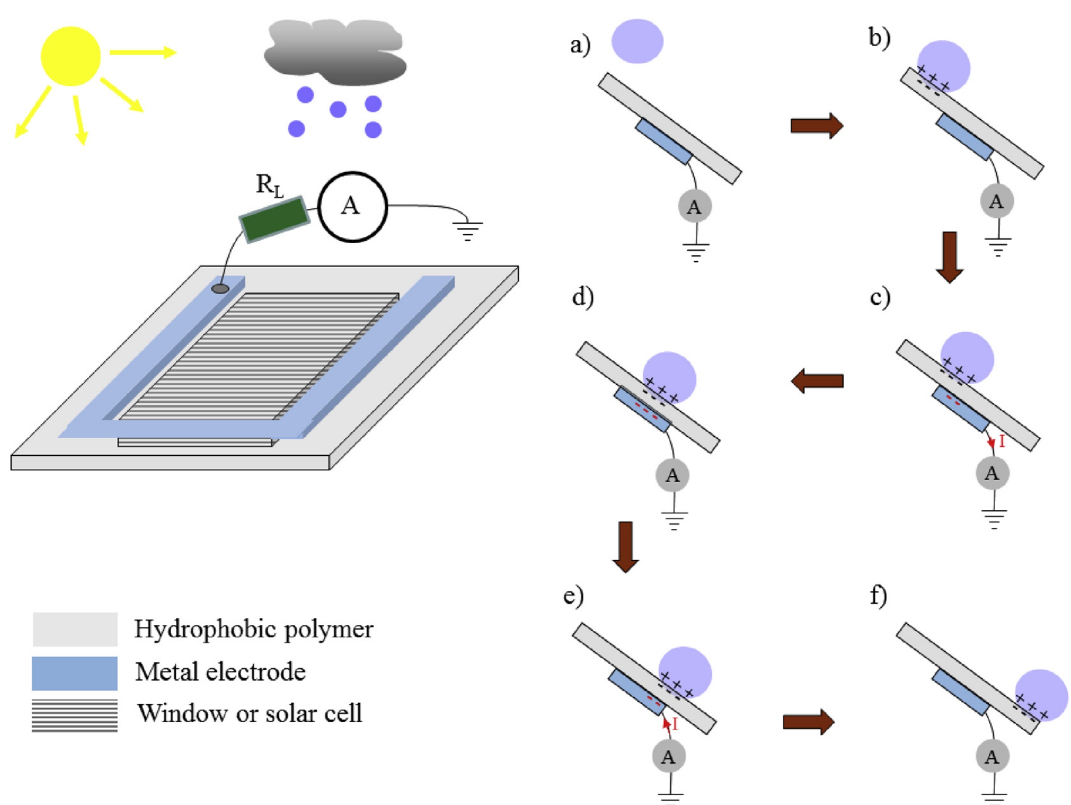

Fig. 1. The large figure on the left shows the experimental setup used to collect droplet-induced charge in front of a window or solar cell. The six figures on the right, a) – f), show the charge collected by the metal electrode as a water droplet rolls over it.