Rain Drop Counting Measurement Sensor with Energy Harvesting Technology of Water Motion †

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Abstract: The damage caused by localized heavy rains has been increasing in recent years, but it is difficult to find ways to protect people and property through existing rainfall measuring devices. This study applied energy harvesting technology through water movement as a sensor technology to monitor instantaneous water bombing phenomenon such as guerrilla storm concentrated in a small area. Water motion active transducer (WMAT) is an energy harvesting device that uses an electric double layer formed when water and a specific polymer are in contact with each other. Transient electron transfer between electrodes formed under the polymer is a main cause of AC peak formation. Measuring the AC peak formed when a raindrop drops onto the surface of the sensor can be used to measure the number of raindrop drops per second.

Keywords: rain drop counting; electrical double layer; water motion; heavy rain; sensor; energy harvesting

1. Introduction

Humans have been measuring rainfall for centuries. Rain is directly related to our agriculture and safety. Due to recent rapid changes in climate, localized heavy rain is increasing, and human life and property damage are occurring. Guerrilla heavy rains are difficult to predict because they occur suddenly in a small area [1]. In addition, since current rainfall measuring apparatuses measure time by hour, it is impossible to measure enormous amounts of rainfall poured over several tens of minutes in a short period of time. Existing radar-based devices are large and expensive, making it difficult to install them tightly in tight spaces. Specialized monitoring devices are needed to count raindrops more conveniently and at lower cost. Our research group first developed energy generation technology through the contact of water droplets and polymer surface in 2014. When water and polymer are in contact, an electric double layer is formed at the interface [2,3]. Most dielectric materials such as various polymers show a permanent polarization property due to their asymmetrical molecular structure. So, the contact between rain drop and dielectric materials make electrical double layer at the interface [4,5]. The electrostatic charges on the surface change the direction of dipoles in dielectric layer. This change in dipole direction caused electron flow between the two electrodes. The process by which the contact of rain drops on dielectric layer generate an AC peak can be explained in three steps. The first step, there was no contact between rain drop and dielectric layer so there is no dipole direction change and no electron flow shown in Figure 1a. Second step, the rain drop was charged positively in contact with negative charged PVP dielectric layer. Electrical double layer was formed at the interface of the rain drop and PVP layer. So negative charges move from second electrode to first electrode to balance the electrons. This movement of charges generate the AC peak in Figure 1b.
2. Materials and Methods

The raindrop counting sensor consists of a substrate, an electrode, a dielectric (polymer layer), and a layer of hydrophobic material shown in Figure 2. For the rain drop counting measurement sensor with patterned ITO, the ITO layer deposited on glass substrate was etched with HCl. Patterned ITO electrode has about 118 nm of thickness and 200 mm of width. Poly-4-vinyl phenol (PVP) is used for dielectric layer. PVP which was a blend of Poly(4-vinylphenol), Propylene glycol monomethyl ether acetate, and Poly (melamine-co-formaldehyde) methylated/butylated (Sigma Aldrich) with mass ratio 2:1:17 was spin-coated at 4000 rpm for 35 s (acceleration speed at 500 rpm for 2 s) and dried at 200 °C for 20 min directly after ultraviolet ozone (UVO, λ = 185 and 254 nm, 100 mW/cm²) exposure for 30 min. The thickness of PVP layer is about 292 nm. To prevent water droplet from attaching to the substrate, EKG-6015 (ETC company, Deggendorf, Germany) was spin-coated at 4000 rpm for 35 s (acceleration speed at 500 rpm for 2 s) and dried at 200 °C for 15 min after UVO (λ = 185 and 254 nm, 100 mW/cm²) exposure for 30 min. The cross-section of the dielectric layer was investigated using a field emission scanning transmission electron microscope (FE-SEM) (JSM-7000F, JEOL, Tokyo, Japan). The water flow was ejected using a syringe pump (Legato 200, KdScientific Inc., Holliston, MA, USA) The open circuit voltage Voc and short circuit current Isc were detected by using 6½-Digit Digital Multimeters and 1.8 MS/s Isolated Digitizers (NI 4070, National Instruments, Austin, TX, USA).

Figure 1. Fundamental operation principle of rain drop counting sensor using water motion active transducer (WMAT): (a) No contact between rain droplet and sensor; (b) Rain droplet was charged positively in contact with the negative charged PVP dielectric layer; (c) Rain droplet moved to the second electrode of sensor and the negative charges of the first electrode moved to the second electrode.

Figure 2. Schematic design and cross-sectional SEM image of the rain drop counting measurement sensor using WMAT technology.
3. Results and Conclusions

The polymer surface is negatively charged and the water is instantaneously positively charged. In this case, when two electrodes are placed under the polymer, electron transfer phenomenon occurs. The movement of electrons generates an AC peak-like voltage, which can be used to measure the drop counting frequency of raindrops in real time. The accuracy of this sensor was measured by dropping water droplets of about 30 uL at various frequencies through a droplet discharge device. The AC peak, which is generated every time water drops, is measured by digital multi-meter, and a device that counts one peak by one water droplet through NI Labview program (National Instruments, USA) has been developed. The developed sensor was able to measure from 2 to 6 droplets per second, and it was possible to measure water droplets per second, cumulative water droplets, and average water droplets per second using WMAT energy harvesting technology.

![Figure 3. Number of rain drop results per second using measured voltage signal by WMAT in various environments from 2 to 6 of rain drops.](image)

**Author Contributions:** S.-H.K. designed the experiments and studied in-depth the concept of rain drop counting. S.-H.K. and W.K.K. performed main experiments, fabricated devices and the analysis of the data.

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**Conflicts of Interest:** The authors (Soon-Hyung Kwon and Won Keun Kim) declare no conflict of interest.

**References**


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