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Piezo-Pyro-Photo-electric Energy Harvesting with Smart Materials based Flag

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Abstract: This paper aims to develop a novel concept for energy harvesting via flexible inverted flags combining photovoltaic cells with piezoelectric flexible films. Using technology currently available, we have designed and fabricated piezo-pyro-photo-electric harvesters made of polyvinylidene fluoride (PVDF) piezoelectric elements combined with mini solar panels made of silicon. Experimental measurements of the motion dynamics and power generation were collected for the flags when subjected to wind, heat, and light sources simultaneously and individually. Results indicate a significant improvement in energy harvesting capability compared to isolated single piezoelectric devices. Thus, we anticipate a substantial impact of piezo-pyro-photo-electric energy harvesting device applications where remote power generation is needed. The Flag uses flexible piezoelectric and pyroelectric strips and flexible photovoltaic cells panel. The piezo-pyro-simultaneously generates power through movement and heat, respectively, while the photovoltaic cells harvest solar energy to produce electric power. The beauty of this Flag is to develop power day and night depending on the energy sources available. The basic concept is presented and validated by laboratory experiments with controlled airflow, light, and infrared heat. The maximum voltage generated was 60 mV when the Flag was simultaneously exposed to low-level wind, thermal and light energies.

Keywords: Pyroelectricity, Piezoelectricity, Photovoltaic, PVDF, Energy harvesting.

1. Introduction

This Flags are not just flown to display patriotism but can be used to generate electric energy from wind, light, and heat from the Sun. Energy harvesting is reusing ambient or wasted energy from a system to generate useful power. Within small-scale applications, piezoelectric devices are recognized as one of the most promising solutions for converting wasted energy into electricity [1]. Energy harvesting from base vibrations/excitation using piezoelectric elements has received the most attention. Renewable energy harvesting from ambient sources has gained increased attention due to increasing carbon emissions from conventional fossil energy in the past decades. The last decade has witnessed advances in energy-harvesting technology due to the rapid growth of the industrial economy and world population, and fossil fuels are no longer sufficient to meet energy demands. Furthermore, there is a significant issue of global warming and changes in atmospheric conditions all around the globe. Self-powered techniques, such as piezoelectric, pyroelectric, triboelectric, thermoelectric, and electromagnetic principles, are being applied to harvest energy in the ambient environment to power small electronic devices, sensors, and IoT nodes. [2]. These are of crucial importance for long-term energy needs and sustainable development. However, these ambient energy sources are unavailable simultaneously, depending on day/night, weather conditions, or working conditions, including in other states. However, several attempts at hybrid energy cells have been achieved for scavenging two kinds of energies. A concept of a hybrid energy harvester is to develop a technology to harvest these energies using integrated devices simultaneously/individually or in a system so that the devices can be powered by using whatever energy is available in their working environment [3]. Authors have proposed and demonstrated a hybrid energy cell that can simultaneously harvest thermal, mechanical, and solar energies. The authors also stated that their multimode energy cell has potential applications for driving micro/nanoelectronics systems. Li et al. have proposed flexible piezoelectric and pyroelectric nanogenerators based on PAN/TMAB nanocomposite fiber mats for self-power multifunctional sensors [4-5]. The PAN/TMAB-4 nanofiber mats generated a high voltage of up to 2.56 V and high power of 0.19 μW upon shape deformation and exhibited linear voltage response to a thermal gradient.

We aim to develop an "Energy-Harvesting Flag" that generates electric power using wind, thermal and solar energy via piezoelectric, pyroelectric materials, and silicon flexible solar cell panel. Since generation from a single piezoelectric device is expected to be low, a novel approach would be to embed the piezoelectric Flag with photovoltaic cells and harvest energy from wind and solar sources within the same device. It is an attempt to develop low-cost technology to power autonomous sensors and devices in remote locations. This technology best suits the 'install & forget' type of sensors. It is worth mentioning that this type of energy-harvesting Flag can power small-scale portable electronics that can be used for environmental sensing. This research presents preliminary and qualitative results from the investigation of ambient energy harvesting, such as experimental wind, thermal, and solar sources.

The prototype novel 'Flag' was developed as part of a research effort to create cheap and sustainable energy-harvesting solutions that can be deployed and left to generate electric energy with little or no maintenance. Under experimental conditions utilized, the voltage generated was 60 mV.

2. Principle of Operation of the Energy Harvesting Flag

The operation of the Flag is based on the following principles:

Pyroelectric Effect

The principle of the pyroelectric effect states that the spontaneous polarization in pyroelectric material is associated with temperature. A variation of the temperature in the material causes the generation of free charges on the surface perpendicular to the polarization direction. The generated charges yield a voltage across the transducer before an external circuit or internal resistance releases them. The relationship between the generated charges dQ and the temperature variation dT is shown below:

$$I_p = dQ/dt = A.p. \, dT/dt,$$

where Ip is the pyroelectric current generated, A is the surface area which is covered by an electrode, p is the pyroelectric coefficient. Without taking the temperature dependence of p into account, it shows clearly that a significant and rapid temperature variation is a favorable condition for generating high electrical power

Photovoltaics

The photovoltaic cell is constructed with crystalline silicon, which is produced exclusively for use in photovoltaic cells. The process of creating electric energy via solar energy converts light (photons) into electrical propulsion, known as the photovoltaic effect (PV). Contained within the photon of light contains, the number or rate of energy varies depending on the wavelength and spectrum of solar-generated. When the photon is in violation or in contact with the solar panel, solar panels will somewhat absorb photons. The solar panels absorb not all photons because it depends on the type of semiconductor materials used to produce the solar panels. Photon energy at certain levels is able to break the bonding electrons from atoms to produce electricity. This energy level is known as band-gap energy, measured in units of electron-volts. A material with band-gap energy between 1 eV and 1.8 eV is the best material and has a high efficiency of energy production.

Piezoelectricity

Piezoelectric Energy Harvesting is based on the piezoelectric effect. The essence of the piezoelectric effect works as follows: by applying mechanical stress to a crystal, one can generate a voltage or potential energy difference and, thus, a current. The piezoelectric generator principle:-The conversion chain starts with a mechanical energy source from vibration. The vibrations are converted into electricity via piezoelectric element. Piezoelectric generators work due to the piezoelectric effect. This is the ability of certain materials to create electrical potential when responding to mechanical changes. To put it more simply, when compressed or expanded or otherwise changing shape a piezoelectric material will output some voltage.

3. Experimental

The energy harvesting flag is designed and created using flexible photovoltaic cells and flexible piezoelectric/pyroelectric PVDF strips. Photovoltaics allows the Flag to convert solar radiation, i.e., Sunlight, into electricity. With piezoelectric and pyroelectric strips, the Flag generates power through movement and solar heat, respectively. The Flag is tested via a table fan to generate wind and a thermal light bulb to generate heat and light to activate pyroelectric strips and solar cells.

The detailed pictorial representation of the Flag with all the functional components is depicted in Fig. 1 and Fig. 2.

Fig. 1. An inverted flag with a mini flexible solar panel and piezoelectric/pyroelectric transducer strips.

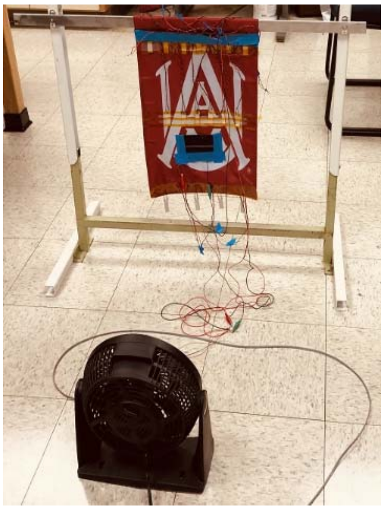

Fig. 2. An inverted flag with a mini solar panel and piezoelectric/pyroelectric transducer strips with a table fan to generate wind.

4. Results and Discussion

Fig. 3 shows the voltage generated from wind/fan speed and heat and light via a thermal-light bulb. It can be seen from Fig. 4 that the voltage generated adds up when all three energy sources are functional.

The charge generation process is predominated by the orientational change in dipole induced by temperature fluctuations in the pyroelectric PVDF film. The temperature of the PVDF film changes when the turbulence in the solar illumination intensity changes; the dipoles oscillate to either a more considerable or lower degree. The changes in the dipole oscillation state cause a distribution of free charges at the electrodes. A charge flow is generated through the PVDF film, thus creating a pyroelectric current to balance the charge distribution. The open circuit voltage (V) is commonly expressed as:

$$V = (p.h\Delta T)/\varepsilon,$$

where ε is the permittivity in the polarization direction at constant stress, p is the pyroelectric coefficient, and h is the thickness of the PVDF film.

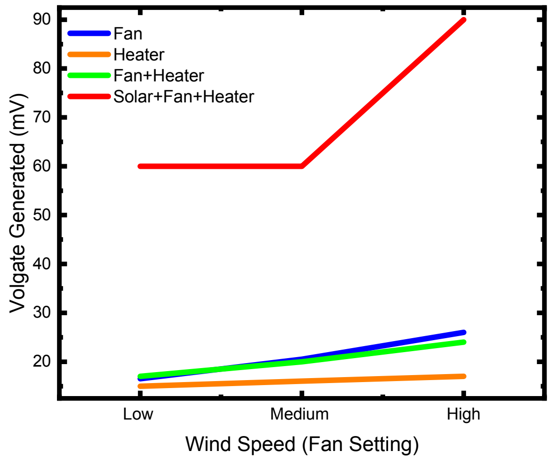

Fig. 3. The variation of voltage generated versus wind/fan speed [low: 0.8 m/s; medium: 1.4 m/s; high: 1.9 m/s], heat [29 °C – 34 °C], and light [0.2 W/m^2].

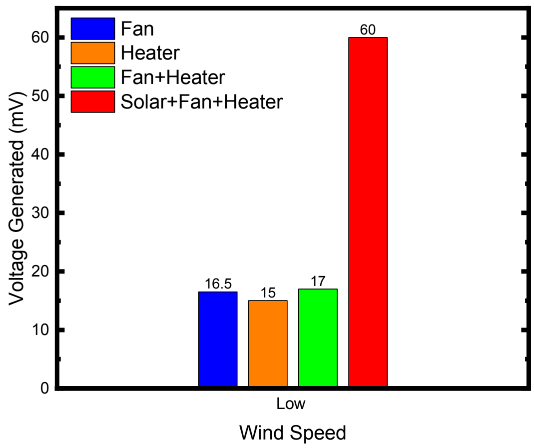

Fig. 4. A bar chart showing voltage generated individually versus heat and wind and simultaneously light, heat, and wind.

When there is wind flow, there will be a vibration, and PVDF film will generate voltage. It is worth mentioning the PVDF film is ferroelectric and well-known for its co-exhibition of both piezoelectric

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and pyroelectric effects. Thus PVDF becoming a multi-sources harvester.

Since a flexible solar cell panel is also attached to the Flag, it will generate voltage during Sunlight via a photovoltaic effect. All the voltages will add up with a well-designed electronic circuit.

5. Conclusion

Based on the experiments performed on the designed Flag, the following conclusions can be drawn:

1. Designed and demonstrated a piezoelectric-pyroelectric-photoelectric-based power harvesting Flag using intelligent materials such as PVDF and silicon.
2. Investigations revealed that using photovoltaic solar panels might help increase or boost the power yield of the system investigated.
3. The maximum voltage generated for the unique energy harvesting Flag was 60 mV under experimental conditions. However, power harvesting voltage can be increased by using enhanced input energy sources.
4. The power harvested obtained can be used for low-power devices and meet future microdevices demand.
5. Further experiments should be performed under real-life ambient sources of energy day and night and power stored for needed devices.

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