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Flexible piezoelectric polymer-based energy harvesting system for roadway applications

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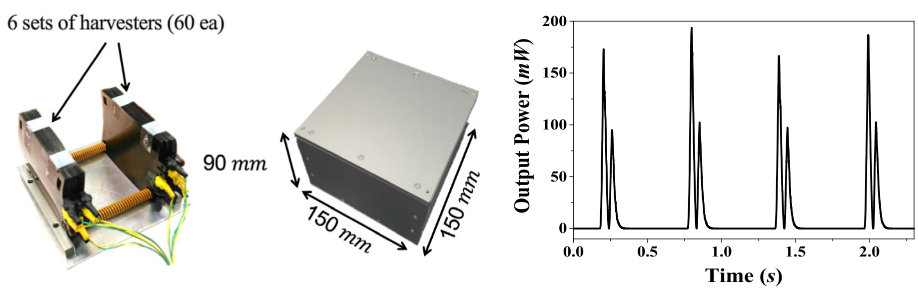
HIGHLIGHTS

- PVDF based piezoelectric energy harvesters are demonstrated for road applications.
- Low impedance and high power output are achieved by effective parallel connection.
- The harvesters exhibit stable performance and durability for over million cycles.
- Module with 15 cm × 15 cm sides exhibits 0.2 W output with 8 W/m^2 power density.

GRAPHICAL ABSTRACT



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ABSTRACT

Interest in energy harvesters has grown rapidly over the last decade. The research effort in large-scale energy harvesting has mainly focused on piezoelectric ceramic based devices, due to its high piezoelectric constants. In this study, we demonstrate a piezoelectric energy harvester module based on polyvinylidene fluoride (PVDF) polymer for roadway applications. Flexible energy harvesters are fabricated with PVDF films and it exhibited stable performance and durability over the repeated number of bending cycles. In order to structurally optimize the design, finite element analysis was performed on two possible module configuration, with detailed input conditions on how the flexible energy harvester must be bent. A piezoelectric energy harvester module is then constructed with the fabricated unit energy harvesters inserted in the vertical direction, with initial radii of curvature as high as possible. The module was tested with a model mobile load system (MMLS3) and exhibited up to 200 mW instantaneous power output across a 40 kΩ resistor. The power output scaled linearly with the number of parallel connected harvesters. The calculated power density at this impedance reaches up to 8.9 W/m^2, suggesting that the flexible energy harvesters based on the piezoelectric polymers may provide energy density as high as those based on piezoelectric ceramics.

1. Introduction

With the advent of environmental issues such as climate change, search for sustainable energy sources has become a crucial issue [1–3]. Along with this effort, both energy harvesting from ambient energy sources and increasing energy efficiency of existing appliances have received a significant amount of research attention [4–7]. Piezoelectric energy harvester modules that generate electricity from human activity have recently been demonstrated on soccer fields, train stations or high school corridors. In addition, the energy efficiency of lighting and electronics have

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increased significantly by the use of light emitting diode (LED) and low-power electronics design over the past decade [8–13].

On the other hand, the energy efficiency of automobiles remains fundamentally limited. M. Kromer estimated that the overall energy efficiency of consumer vehicles is approximately 15%, after various waste mechanisms or dissipations including wasted heat on engines, idle time, drivetrain, and wheels [14]. Among those mechanisms, 20% of the overall energy is lost to the wheels of vehicles. This energy is dissipated as heat, vibration or roadway deformation. According to a report by Roshani et al., the amount of this dissipated energy exceeds 4 GJ per lane per day, assuming 100 trucks pass by at 80 km/h [15].

With the existing energy harvesting technology, various attempts have been made to convert this dissipated energy into electricity. Ting et al. designed a mechanical system to convert weight exerted by cars into hydraulic flow [16]. Jiang et al. designed a lead zirconate titanate (PZT) piezoelectric module that harvested traffic-induced pavement deformations [17]. Xiong and Wang demonstrated a piezoelectric harvester module with on-site installation in Virginia, USA [18]. On the industry side, several start-up companies such as Treevolt or Innowattech demonstrated pilot projects for energy-generating roadways. Treevolt successfully installed 120 m of energy harvesters in Medellin, South Africa and demonstrated 3 kW energy generation capability [19].

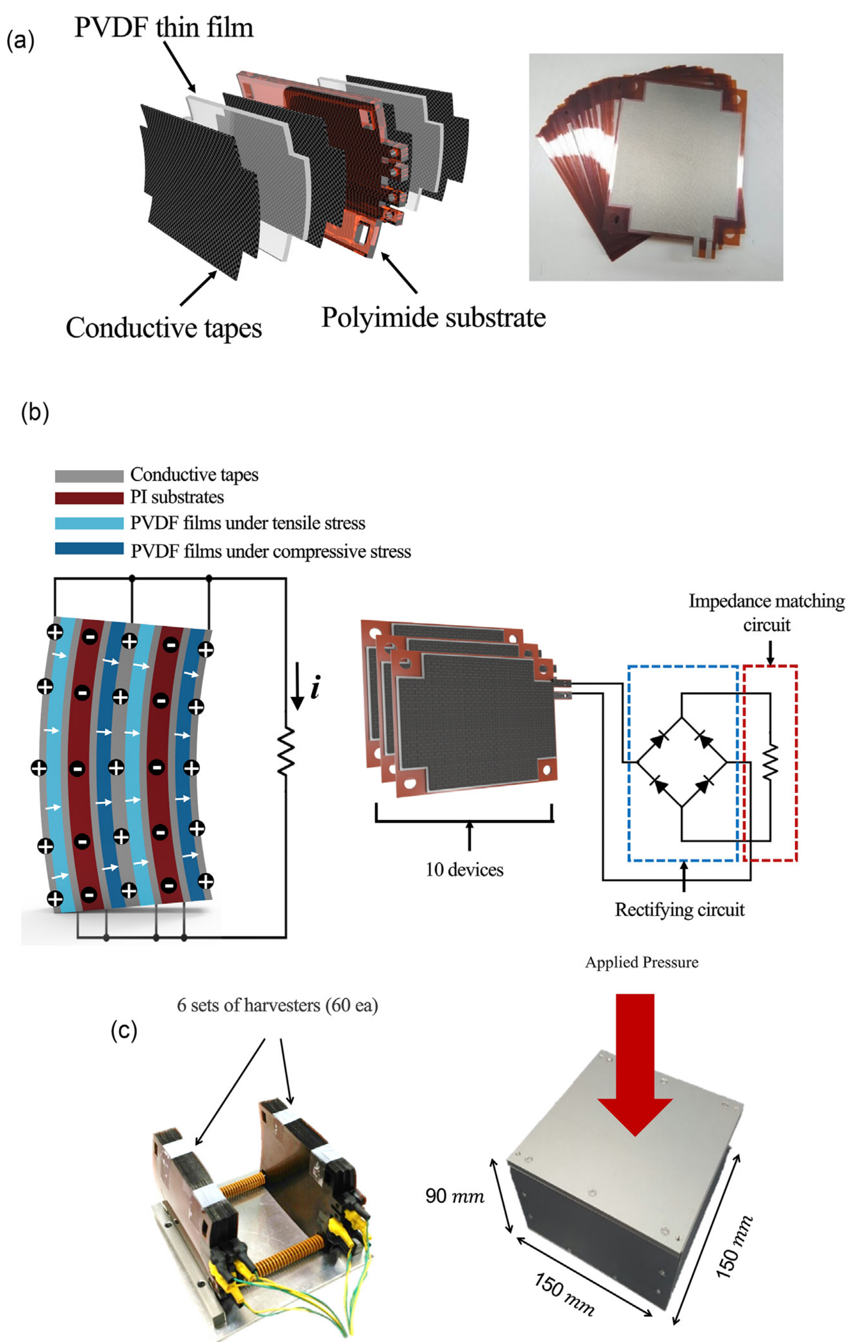

Fig. 1. Single energy harvester device designed with PVDF thin film. (a) Schematic and image of the bi-morph structure energy harvester. The device consists of nickel-based conductive fabric tapes (15 μm), PVDF thin film (110 μm), and polyimide substrate (300 μm). (b) Parallel connection of unit harvesters. On both sides, the PVDF films have the same poling direction, resulting in the same polarity (positive) on both outer surfaces. While the poling directions are the same, the opposite stress directions result in oppositely directed polarization. The stacked unit harvesters are then connected to rectifying circuit and impedance matching circuit. (c) The interior and exterior of constructed energy harvester module, with stacked energy harvesters inside.