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Ocean-based electricity generating system utilizing the electrochemical conversion of wave energy by ionic polymer-metal composites

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ABSTRACT

In this research we used an energy harvesting system based on ionic polymer–metal composites (IPMCs) to absorb the kinetic energy of the ocean waves and generate electricity. The experimental results showed that IPMC materials have many advantages, including softness and durability; they also respond rapidly to wave parameters such as frequency, amplitude, and wavelength. In addition, the 296-day recorded data showed that the average power density generated each day remained stable at approximately 245 μW/m^2, the degradation of the IPMC's electrical performance in long-term operation being trivial.

1. Introduction

The world's growing demand for energy is a great challenge. If sustainable development is to be achieved, it is necessary to find alternatives to fossil fuels. Among the possible sources of renewable energy, ocean waves have the highest energy density, and researchers have been working on methods to harness their power for the benefit of mankind [1–8].

Ocean wave energy may be transformed into electricity by devices or power absorbers specifically manufactured for this purpose. Piezoelectric materials have already been utilized to convert kinetic energy into electrical energy and have played an important role in electrical energy generation in a number of applications [9]. For example, macro fiber composites (MFCs) have been investigated by Youngsu Cha [10]. However, piezoelectric materials are generally brittle and do not respond actively at low frequencies, which limits their usefulness. This problem can be overcome by using IPMCs due to their durability, frequency response, and directional response [9]. As described in [11–12], IPMCs can be used as electro-mechanical materials. The authors of these works have described the mode of operation of IPMC materials and have developed a theory for electroactuators with single charge carrier ionomers that reveals the interplay between the effects of electrostatic pressure resulting from ionic repulsion, and of the steric strain caused by the volume of ions in the double layer.

Ionic polymer–metal composites, which consist of two metal electrodes with an ion-conducting polymer between them, are a promising class of electroactive ionic polymers that can be utilized as sensors, actuators or energy harvesters [13]. Generally, perfluorinated polymers (sulfonated or carboxylated) are employed for IPMCs [14]. Perfluorinated sulfonic acid ionomeric polymers are synthesized by copolymerization of sulfonyl fluoride vinyl ether and tetrafluoroethylene [14–16]. Nafion is a perfluorinated sulfonic acid ionomer membrane that has a Teflon-like backbone and short side-chains terminated by sulfonic acid groups, with counter ions, such as H^+, Li^+, Na^+ and K^+, and hydrophobic fluorocarbon and hydrophilic ionic phases. In a Nafion®-based IPMC, the SO_3^- groups form ionic terminations on each side branch, as shown in Fig. 1a. Consequently only cations can freely move in the membrane while the anions (SO_3^- groups) are fixed to the backbone. Fig. 1b shows the mechanism by which IPMCs generate electricity. When the IPMC is mechanically bent, the hydrated cations on the compressed side of membrane move towards the stretched side of the membrane, resulting in an imbalance in the number of cations in contact with each electrode, and producing an output voltage across the membrane.

Based on this fundamental property of IPMCs, a movable power system was designed which harvests the energy of both vertical waves and horizontal ocean currents to supply electricity to stand-alone offshore plants. The system comprises a main buoy and 18 modules with IPMC

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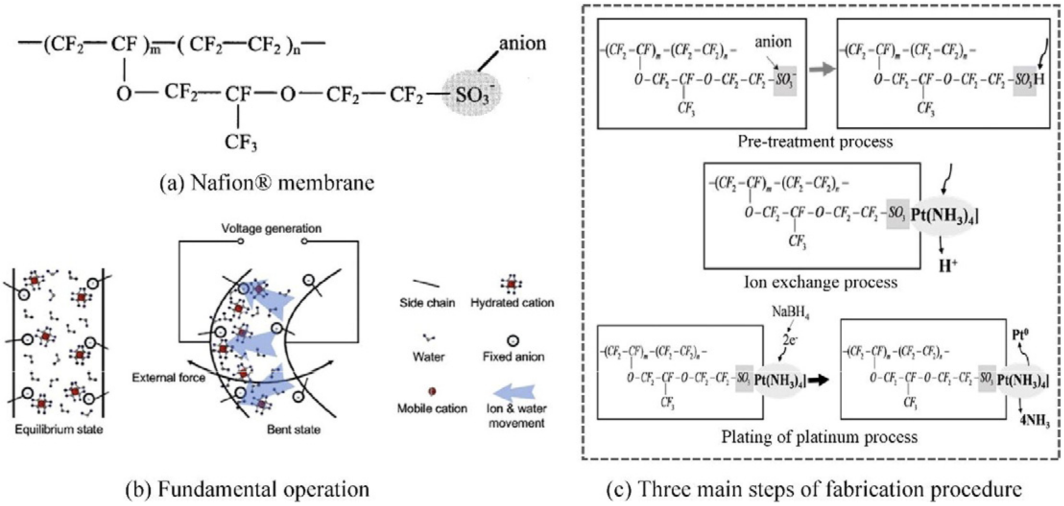

Fig. 1. IPMC characteristics: (a) chemical structure of Nafion® membrane; (b) fundamental principles of electricity generation using IPMC; (c) three main steps of fabrication procedure.

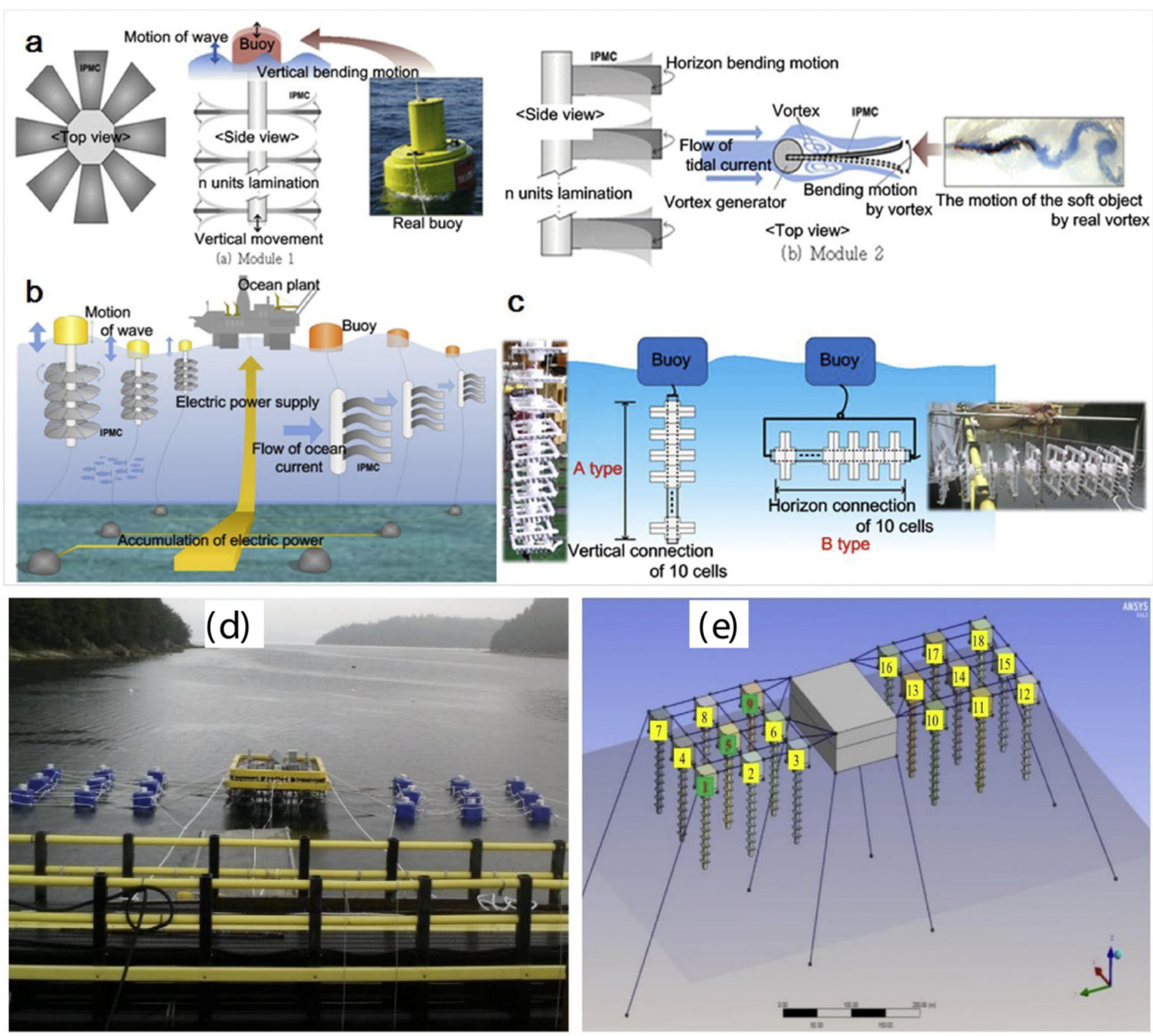

Fig. 2. Conceptual design of the ocean kinetic energy harvesting structure with an electrochemical material consisting of IPMC: (a) illustration of a compact movable power system utilizing both vertical waves and horizontal ocean currents with a vortex; (b) illustration of the ocean kinetic energy harvesting structure made of an electrochemical material consisting of IPMC, which supplies electricity to stand-alone offshore plants; (c) design and fabrication of a transverse component for the vertical waves and a longitudinal component for the horizontal ocean currents; (d) ocean kinetic energy harvesting modules installed in the ocean; (e) ocean kinetic energy harvesting system modeled with ANSYS AQWA.