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Enhancement of Power Output by using Alginate Immobilized Algae in Biophotovoltaic Devices

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We report for the first time a photosynthetically active algae immobilized in alginate gel within a fuel cell design for generation of bioelectricity. The algal-alginate biofilm was utilized within a biophotovoltaics (BPV) device developed for direct bioelectricity generation from photosynthesis. A peak power output of 0.289 mWm^{-2} with an increase of 18% in power output compared to conventional suspension culture BPV device was observed. The increase in maximum power density was correlated to the maximum relative electron transport rate (rETRm). The semi-dry type of photosynthetically active biofilm proposed in this work may offer significantly improved performances in terms of fuel cell design, bioelectricity generation, oxygen production and CO_2 reduction.

Light has been used as an energy input in a variety of photovoltaic devices. Wu *et al*. (2011) produced a near-infrared laser-driven organic photovoltaic device (OPV), which can convert laser light to electrical power using a blend of poly(3-hexylthiophene) (P3HT) and [6,6]-phenyl-C61-butyric acid methyl ester (PCBM) with maximum power output of 2.10 μW[1]. The performance of the OPV was enhanced based on a blend of P3HT and PCBM, through the introduction of NaYF4:Yb/Er NCs with maximum power output of 9.05 μW[2]. Dye-sensitized photovoltaic devices generating a maximum power output of 22.2 μW when illuminated by 980 nm laser light, have been suggested as a potential electrical source for powering nanodevices under the skin[3]. Recently, Hsiao *et al*. (2016) developed a biocompatible OPV using low-toxicity β-carotene and perylene materials which, when stimulated with a white light LED, generated 35.34 μW power output[4]. Microorganisms such as cyanobacteria and microalgae that carry out conventional and bacterial photosynthesis, have high resilience and can live in a wide range of conditions from high temperatures to low light conditions[5]. The cultivation of these photosynthetic organisms for producing sustainable fuels and chemical feedstock is on the increase[6]. Microalgae are amongst the most efficient photosynthetic organisms, with fast growth rates, diverse products and tolerance to extreme environments[5]. These photosynthetic organisms successfully harvest solar energy and convert this energy into chemical energy[7,8], and store this energy in the form of oils, carbohydrates and proteins[9]. Recent studies have reported the use of microalgae in fuel cells (FCs), giving rise to a novel range of systems based on biological photovoltaic devices or BPVs[10,11]. Photo-microbial fuel cells have been developed based on the utilization of cyanobacteria for hydrogen generation[12] and electricity generation using 2-hydroxy-1,4-naphthoquinone as an electron shuttle between the algae cells and a carbon-cloth anode[13]. The generation of bioelectricity directly from algal photosynthesis using biophotovoltaic (BPV) devices have been reported. Bombelli *et al*. (2011) used whole cells as well as thylakoid membranes isolated from the Cyanobacterium *Synechocystis* and generated total power output of 4.71 and 9.28 nW μmol/Chl[10]. Inglesby *et al*. (2013) generated 1.12×10^{-4} W m^{-2} using BPV with biofilm of another Cyanobacterium *Arthrospira* on ITO-Polyethyleneterephthalate anode[14]. Ng *et al*. (2014) used biofilms of two species of the Chorophyte *Chlorella* and two species of Cyanobacteria *Spirulina* and *Synechococcus* on ITO anodes and obtained increased power output ranging from 1.12×10^{-4} to 3.13×10^{-4} W m^{-2}[8]. Replacing ITO with reduced graphene oxide (rGO) anode, using the Langmuir-Blodgett method, power output was further increased by 119% compared to the former type of anode[15].

Various biological components have been introduced into fuel cells (FCs), giving rise to biophotovoltaic devices (BPVs), BPVs produce electricity from light energy via the light harvesting apparatus of the

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