

Development of an Eco-Friendly Bio-Battery Using Cucumber and NaCl as Ion Sources and Tapioca Flour as a Matrix

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Abstract

The use of natural materials in bio-battery research plays a crucial role in the search for environmentally friendly and cost-effective energy solutions. This study aims to determine the optimal composition of fermented cucumber juice and the addition of NaCl at the fermentation's optimal point to produce maximum current and voltage. Graphite sheets were used as the anode and aluminum sheets as the cathode. The cucumber juice was fermented for varying durations: 0, 24, 48, 72, 96, 120, 144, and 168 hours. Tapioca flour was gradually added until a solid electrolyte was formed. This solid electrolyte was then placed between the graphite and aluminum sheets to measure current and voltage output. At the optimal fermentation time, varying amounts of NaCl (0.5 g, 1 g, 1.5 g, 2 g, 2.5 g, and 3 g) were added to determine the best-performing composition. The results showed that the optimal composition without NaCl was achieved at 48 hours of fermentation, yielding a current of 0.76 mA and a voltage of 0.695 V. With the addition of NaCl, the maximum current and voltage reached 2.01 mA and 0.704 V, respectively, with the optimal NaCl mass being 1.5 g. This research shows great promise for further development due to its simple methodology and the use of low-cost, eco-friendly materials.

Keywords: bio-battery, cucumber juice, NaCl, current, voltage

INTRODUCTION

Energy plays a vital role in modern life and has become a primary necessity. Nearly all sectors of human activity depend on energy to function effectively. In Indonesia, the current high demand for electricity is not matched by the available energy supply (Agung, 2013). This imbalance has led to an unavoidable electricity crisis, highlighting the urgent need to explore and develop alternative energy sources that are both renewable and environmentally friendly.

Batteries are a crucial source of energy in everyday life, widely used in wall clocks, television remotes, radios, flashlights, and various electronic devices (Purwati et al., 2017). Batteries are generally categorized into two types: primary batteries, which are disposable and intended for single use, and secondary batteries, which are

rechargeable and can be used multiple times (Afif et al., 2015). However, commonly used single-use dry batteries often contain hazardous and toxic waste materials (B3), such as mercury, manganese, lead, nickel, lithium, and cadmium (Purwati et al., 2017). Improper disposal of these materials can lead to serious environmental pollution and pose significant health risks to humans, including damage to the central nervous system, kidneys, reproductive system, and even cancer (Purwati et al., 2017).

Bio-batteries represent an emerging and promising field in the development of renewable energy technologies, harnessing the energy potential found in biological systems (Praswanto & Setyawan, 2023). These batteries utilize organic compounds as energy sources and are capable of generating electrical energy through the biological activity of living organisms (Erviana et al., 2020).

The process involves the transfer of electrons through a conductive medium between two electrodes an anode and a cathode resulting in the generation of electric current and voltage differences (Mathura & Abdullah, 2021).

Fruits and vegetables, in addition to serving as essential food sources rich in vitamins for humans, also possess the potential to generate electricity due to their high acid content. The presence of free electrons and ions in these substances or their extracts allows for the flow of electric current (Safitri et al., 2023; Anjarsari et al., 2024; Yanti et al., 2024; Hasrolita et al., 2024). Therefore, studies on the utilization of bio-batteries to convert the electrical potential of organic materials such as fruits and vegetables are highly relevant within the context of renewable energy development.

Previous research has shown that eco-friendly bio-batteries derived from fruits and vegetables can generate electrical energy. A study conducted by Jauharah (2013) revealed that citrus fruit waste can be utilized as a source of electrical energy, producing a current of 0.93 mA and a voltage of 2.72 volts. Remarkably, the bio-battery was able to power an LED for 75 hours, demonstrating significant potential for the development of renewable energy technologies based on abundant organic resources.

Ikhsani (2021) found that pH has a significant influence on the voltage produced by decayed fruit solutions. For example, cucumber solution with a pH of 4.13, when used in combination with magnesium graphite in a series circuit, generated a current of 2.4 amperes and a voltage of 4.04 volts. These results indicate that fruits and vegetables with low pH values such as tomatoes (pH 3.57), cabbage (pH 3.93), and carrots (pH 4.2) also exhibit promising potential to generate electrical energy through electrochemical processes.

In addition to being a potential alternative energy source, cucumber is also a widely consumed fruit vegetable. Its high water content makes it ideal for fresh consumption, complemented by its richness in essential minerals (Sari et al., 2023). The combination of its nutritional properties and electrochemical potential suggests that cucumbers not only offer health benefits through direct consumption but also hold promise as a contributor to alternative energy technologies.

Cucumbers contain a variety of ionic species such as potassium (K^+), nitrate (NO_3^-), chloride (Cl^-), and phosphate (HPO_4^{2-}), which are the primary components in cucumber juice. Studies have shown that K^+ is the dominant cation within cucumber tissues, while NO_3^- , Cl^- , and HPO_4^{2-} are the major inorganic anions present in cucumber extracts (Cataldi et al., 2003; Jayashree et al., 2015). In addition, other ions such as sodium (Na^+), ammonium (NH_4^+), magnesium (Mg^{2+}), and calcium (Ca^{2+}) have also been identified in the tissue composition, with varying relative concentrations depending on the vegetable samples analyzed (Cataldi et al., 2003; Jayashree et al., 2015). With this diverse ionic composition, cucumbers offer significant potential for application in bio-battery technology, where these components can enhance electrochemical conductivity and support the sustainable performance of alternative energy systems.

NaCl, when dissolved in water, dissociates into sodium (Na^+) and chloride (Cl^-) ions, serving as an important electrolyte in bio-batteries to enhance electrical conductivity (Arti et al., 2020). Research has shown that the addition of NaCl to fruit juices such as pineapple juice can significantly increase the electrical current produced by a bio-battery compared to the use of pure juice alone (Fitrya et al., 2023).

Tapioca flour has shown significant potential as a solid electrolyte material in bio-batteries due to its unique characteristics (Siti et al., 2021). Studies have revealed that tapioca flour is effective in the fabrication of solid biopolymer electrolytes, which not only enhance ionic conductivity but also improve the electrochemical properties of the system (Norman et al., 2023). In addition to serving as an electrolyte, tapioca flour also functions as a binder in the production of heterogeneous catalysts, where variations in composition and sintering temperature influence the characteristics and performance of the catalysts. Furthermore, chemical modification of tapioca flour with polyethylene glycol (PEG) groups has been shown to improve the mechanical behavior and electrochemical performance of silicon anodes in lithium-ion batteries (Shasini et al., 2020). Overall, these findings highlight the potential of tapioca flour in enhancing the functionality and efficiency of solid electrolytes in bio-batteries, thereby contributing meaningfully to the advancement of sustainable alternative energy technologies.

Based on the aforementioned discussion, the researcher is motivated to conduct a study on alternative energy sources through the development of a bio-battery using a simple and environmentally friendly method. The battery's anode will be made from graphite sheets, while the cathode will consist of aluminum sheets. The solid electrolyte will comprise a tapioca flour matrix combined with table salt and fermented cucumber juice as the ion source. The preparation of the solid electrolyte will follow a straightforward mixing process. By utilizing affordable, eco-friendly materials and a simple fabrication approach, this bio-battery is expected to be not only cost-effective but also environmentally sustainable.

MATERIALS DAN METHODS

This study employed several primary materials, including cucumber, NaCl, and tapioca flour. An experimental method was used, with quantitative data collected throughout the process. The research was conducted in several stages, including sample collection, preparation of fermented cucumber juice, and the formulation of the paste. The variables measured in this study were electrical current and voltage.

Preparation of tools and materials was the first essential step to ensure that all components were complete and ready for use. Fresh cucumbers were selected to ensure optimal quality. The cucumbers were thoroughly washed with clean water to remove any dirt or residual contaminants. After peeling, the cucumbers were washed again and blended into a pulp. The fresh cucumber juice was then filtered using a fine sieve, collected into a container, and its pH was measured.

The filtered cucumber juice was divided into seven separate containers for fermentation. Each container was sealed tightly, and fermentation was carried out for 24, 48, 72, 96, 120, 144, and 168 hours. Before the experiment began, the pH of each sample was measured at every fermentation time point.

Next, tapioca flour was mixed with 20 mL of the filtered cucumber juice from each fermentation time. For every mixture, 33 g of tapioca flour was added to form a paste-like solid electrolyte. The bio-battery was then assembled using graphite as the anode and aluminum as the cathode. Electrical current and voltage were measured using a digital multimeter (Sanwa CD800a).

After determining the optimal fermentation time, NaCl was added to the electrolyte in varying amounts: 0.5 g, 1 g, 1.5 g, 2 g, 2.5 g, and 3 g to identify the optimum salt concentration. To analyze changes in electrical current and voltage,

the resistance of both the liquid and solid electrolyte was measured using the same digital multimeter (Sanwa CD800a), providing data on their electrical conductivity.

RESULT AND DISCUSSION

Measurements of bio-battery parameters utilizing cucumber juice were carried out with fermentation durations ranging from 0 hours (fresh cucumber) to 168 hours (7 days). A volume of 20 mL of cucumber juice was used as the ion source, combined with 33 grams of tapioca flour as the matrix. The optimal fermentation point was identified at 48 hours. At this condition, additional experiments were conducted by varying the amount of NaCl added—0.5 g, 1 g, 1.5 g, 2 g, 2.5 g, and 3 g—while maintaining the tapioca flour at 33 grams. These measurements yielded data in the form of electric current and voltage outputs.

3.1. Fermentation of Cucumber Juice as an Electrolyte

The effect of cucumber juice fermentation, combined with tapioca flour, on the performance of the bio-battery—measured through current and voltage parameters—is presented in Figure 3.1 and Table 3.1. The data show that the initial pH of the fresh cucumber juice was 5.2, which dropped significantly to 3.1 after 24 hours of fermentation. From 48 hours onward to 168 hours, the pH stabilized at approximately 2.9.

A similar phenomenon regarding the stabilization of pH after day three was also observed in lactic acid (LA) fermentation involving *Lactobacillus plantarum* (LBF) over a seven-day fermentation period. Experimental results showed that the pH of LA rapidly decreased from 7.0 to 3.8 within the first three days, and then remained nearly constant at approximately 3.9 through

day seven (Lorenz et al., 2023). A related study conducted by Liang et al. (2016) measured the pH of Paocai, a traditional fermented vegetable dish made from cabbage, cowpeas, carrots, ginger, and pepper, all chopped and immersed in a brine solution within sterilized jars. The jars were sealed with water and kept at room temperature for fermentation over 30 days. The pH dropped significantly from 7.5 on day one to 3.03 within the first five days and subsequently stabilized until day nine.

The initial current of the battery was 0.51 mA, which increased to 0.59 mA after 24 hours and peaked at 0.76 mA at 48 hours. Subsequently, the current gradually decreased, reaching 0.40 mA at 144 hours and remained stable at 168 hours. The initial voltage of the battery was 0.660 V, slightly increasing to 0.668 V at 24 hours and reaching a peak of 0.695 V at 48 hours. The voltage then gradually declined to 0.422 V at 168 hours.

The measurement of liquid and solid electrolyte resistance was conducted using an ohmmeter as a substitute for Electrochemical Impedance Spectroscopy (EIS) to identify the causes of fluctuations in current and voltage (Rahman et al., 2021). This measurement aimed to determine the conductivity pattern of both liquid and solid electrolytes. As shown in Figure 3.1 and Table 3.1, the resistance of the liquid and solid electrolytes fluctuated, resulting in the observed rise and fall in current and voltage. At the beginning of fermentation (0 hours), the resistance of the liquid electrolyte was 16.58 k Ω , which decreased to 13.20 k Ω at 24 hours and reached its lowest value of 10.15 k Ω at 48 hours. Subsequently, the resistance gradually increased, reaching 22.4 k Ω at 168 hours. For the solid electrolyte, the resistance was initially 35.98 k Ω at 0 hours, sharply decreasing to 27.07 k Ω at

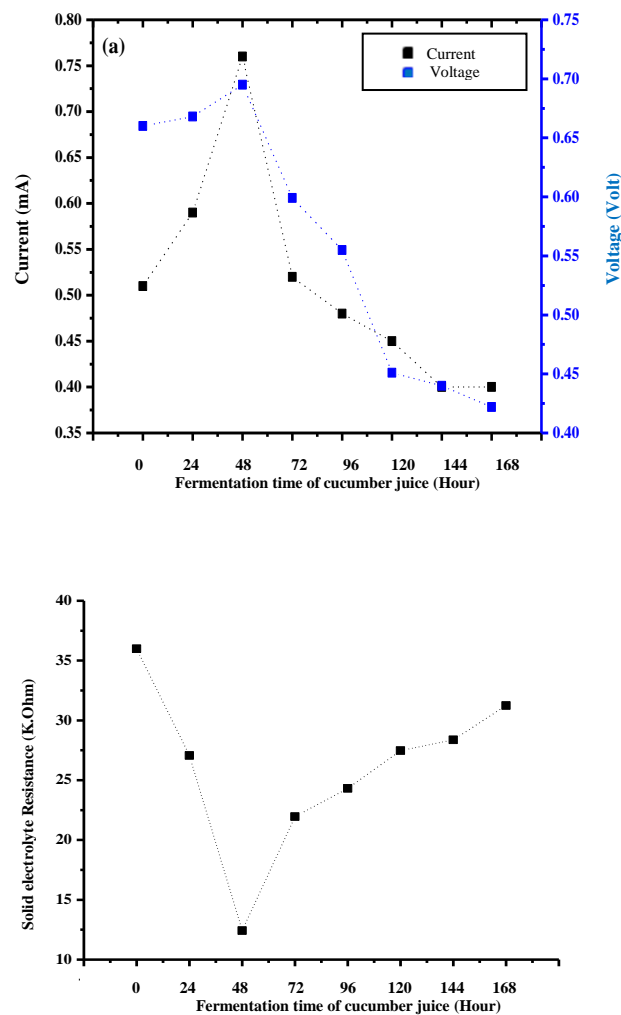


Figure 3.1. (a) Correlation between fermentation duration of cucumber juice, current, and voltage output of the bio-battery; (b) Effect of fermentation duration on the resistance of the solid electrolyte.

Table 3.1. Correlation between the duration of cucumber juice fermentation and the resulting current, voltage, liquid electrolyte resistance, and solid electrolyte resistance in the bio-battery system.

Fermentation time of cucumber juice (Hour)	pH	Current (mA)	Voltage (Volt)	Liquid electrolyte resistance (K.Ohm)	Solid electrolyte resistance (K.Ohm)
0	5,2	0.51	0,660	16,58	35,98
24	3,1	0,59	0,668	13,20	27,07
48	2,9	0,76	0,695	10,15	12,43
72	2,9	0,52	0,599	13,31	21,96
96	2,9	0,48	0,555	15,14	24,32
120	2,9	0,45	0,451	19,93	27,48
144	2,9	0,40	0,440	20,93	28,37
168	2,9	0,40	0,422	22,42	31,24

24 hours and reaching a minimum of 12.43 k Ω at 48 hours. The resistance of the solid electrolyte then gradually increased thereafter.

Based on the research findings, the optimum current and voltage were achieved at 48 hours of fermentation, which also corresponded to the lowest electrolyte resistance, indicating the highest conductivity. These results are supported by a similar study conducted by Suciwati et al. (2019), which investigated the fermentation of lime, lemon, Medan orange, and Pontianak orange for 48, 96, 144, and 192 hours. The study found that the highest pH values, current, and voltage were obtained at 48 hours of fermentation compared to other durations. Another study also noted that prolonged fermentation may lead to undesirable outcomes due to ongoing physical, chemical, and microbial processes, potentially resulting in suboptimal fermentation, as stated by Kim & Fred (2007).

The study conducted by Nur et al. (2021) investigated fermentation at varying durations: 0 hours, 24 hours, 48 hours, and 72 hours. The results revealed a progressive decrease in pH, indicating an increase in the acidity of the material. This pH reduction was attributed to the metabolic activity of microorganisms present in the substrate. During fermentation, these microorganisms actively decompose organic components, leading to the formation of acidic compounds. Correspondingly, the voltage and current output of the bio-battery increased, reaching their peak at the optimal fermentation time, before declining again. The study identified 48 hours as the optimal fermentation duration, producing the highest voltage output of 1.008 V for the albedo solution and 0.956 V for the flavedo solution.

During the fermentation process, the concentration of ions in the electrolyte solution tends to increase over time (Andersen et al., 2015). This phenomenon is driven by the activity of microorganisms such as bacteria and yeasts, which catalyze various biochemical reactions (Liu & Kokare, 2023). These microorganisms break down complex substrates into simpler molecules, releasing ions into the solution (Singh et al., 2016). In addition, the degradation of organic components and cellular autolysis also contribute to the rise in ion concentration. For instance, during alcoholic fermentation, ion concentrations increase significantly due to the production of ethanol and organic acids, which enhance molecular dissociation within the fermentation medium. Studies have shown that the concentrations of ions such as K⁺, Na⁺, Ca²⁺, and Mg²⁺ can rise considerably within a specific timeframe during fermentation (Li et al., 2019).

The fluctuation of conductivity in solid electrolytes containing ions is influenced by the interionic distance. When the ion concentration is too low, the large distance between ions hinders their mobility within the medium. As the number of ionic sources increases, the interionic distance decreases, allowing ions to move more freely. However, if the ion concentration becomes excessively high, ion mobility can again be impeded due to strong electrostatic repulsion between closely spaced ions (Aji et al., 2012).

3.2. Fermented Cucumber Juice (Optimum Fermentation Time) and NaCl as Electrolyte

To enhance the performance of the bio-battery, NaCl was added to the electrolyte. A similar study by Sarah et al. (2024) demonstrated that the addition



of NaCl solution as an electrolyte medium can improve both current and voltage output in bio-batteries. Sodium chloride, when dissolved in water, dissociates into sodium (Na^+) and chloride (Cl^-) ions, thereby acting as an effective electrolyte in the system. The electrical conductivity of NaCl depends on the concentration of the solution; the more diluted the solution, the higher its conductivity due to the increased mobility of ions. The flow of electric current in such systems is driven by the movement of these ions in the solution (Hidayati & Zainul, 2019).

The addition of table salt (NaCl) to fermented cucumber juice was conducted at the 48-hour fermentation point, which corresponds to the optimum condition where the highest current and voltage outputs were achieved. The effect of varying NaCl concentrations on the

current and voltage of the electrolyte solution is presented in Figure 3.2 and Table 3.2. The data show that increasing the mass of table salt from 0.5 grams to 1.5 grams gradually increased the current from 1.37 mA to 2.01 mA. However, further addition up to 3 grams resulted in a decrease in current to 1.06 mA. Similarly, the voltage initially rose from 0.691 V to 0.698 V at 1 gram of NaCl and peaked at 0.704 V with 1.5 grams. Beyond this concentration, additional NaCl reduced the solution's conductivity, as evidenced by a gradual decline in voltage to 0.636 V at 3 grams of NaCl. These findings are consistent with a study by Sutanto and Rohadi (2020), which reported that the addition of 1.5 grams of NaCl significantly increased the average electric current from 0.23 mA to 9.34 mA.

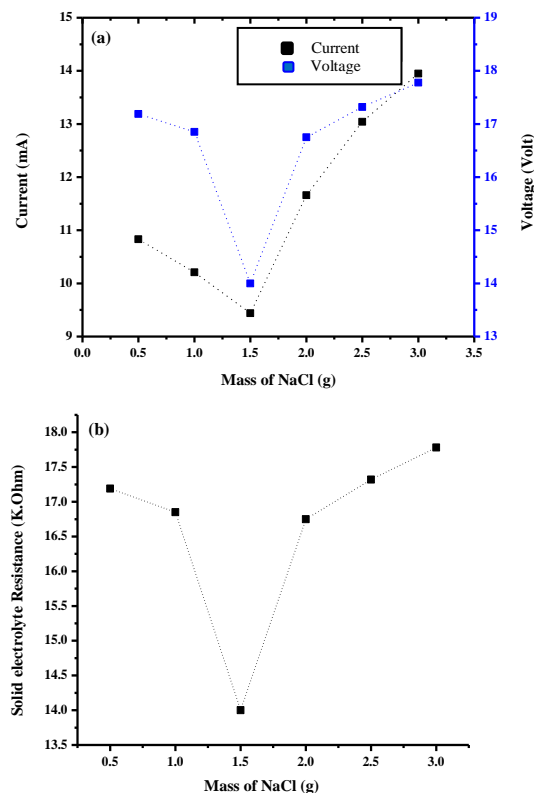


Figure 3.2. Graphs showing (a) the relationship between NaCl mass, electric current, and voltage, and (b) the relationship between NaCl mass and the resistance of the solid electrolyte.

Table 3.2. Relationship between optimum fermentation of cucumber juice and the addition of table salt (NaCl), current, voltage, liquid electrolyte resistance, and solid electrolyte resistance.

Mass of NaCl (gr)	Current (mA)	Voltage (Volt)	Liquid Electrolyte Resistance (K.Ohm)	Solid electrolyte resistance (K.Ohm)
0,5	1,37	0,691	10,83	17,19
1,0	1,65	0,698	10,21	16,85
1,5	2,01	0,704	09,44	14,00
2,0	1,60	0,666	11,66	16,75
2,5	1,31	0,654	13,04	17,32
3,0	1,06	0,636	13,95	17,78

To determine the cause of the fluctuations in current and voltage of the bio-battery, measurements of both liquid and solid electrolyte resistances were conducted. The results indicated that changes in the battery's current and voltage were directly influenced by variations in liquid and solid electrolyte resistance. Both resistances decreased as the mass of NaCl increased, suggesting an enhancement in the conductivity of the electrolytes. Starting from 10.83 k Ω at 0.5 g of NaCl, the resistance continued to decrease, reaching a minimum of 12.43 k Ω at 3 g of NaCl. However, resistance began to rise again when the NaCl mass exceeded 1.5 g, indicating a decline in the conductivity of the solid electrolyte.

A similar study by Cyriac et al. (2022) investigated the effect of sodium iodide (NaI) doping on a polymer blend of sodium carboxymethyl cellulose (NaCMC) and polyvinyl alcohol (PVA) to form solid polymer electrolyte (SPE) films. The films were fabricated using a solution casting technique and subsequently analyzed through Fourier-transform infrared spectroscopy (FTIR), X-ray diffraction (XRD), electrical impedance spectroscopy, thermogravimetric analysis (TGA), and differential scanning calorimetry (DSC). The results revealed that NaI

doping reduced crystallinity, enhanced ionic conductivity up to $2.52 \times 10^{-3} \text{ S cm}^{-1}$ in the sample with 30 wt% NaI (S30), and increased the glass transition temperature (T_g) due to strong interactions between Na^+ cations and oxygen atoms within the polymer chains. Although salt doping slightly reduced thermal stability and mechanical strength, the high ionic transference number (0.99) indicated that ions were the predominant charge carriers. The highly conductive S30 sample was subsequently used in battery fabrication to evaluate its potential application in energy storage devices.

Elmanzalawy et al. (2022) reported a solvent-free synthesis of solid polymer electrolytes (SPEs) based on polyethylene oxide (PEO) with potassium tetraphenylborate (KBPh_4) as a potassium ion source, aiming to enhance the safety and energy density of potassium-based batteries. The formation of two crystalline complexes, PEO/ KBPh_4 , was confirmed, which acted as ion receptors, preventing polymer crosslinking and contact ion pair formation. This led to a reduction in glass transition temperature and an increase in ionic conductivity up to $1.1 \times 10^{-4} \text{ S cm}^{-1}$ at 55°C . A maximum conductivity of $1.8 \times 10^{-3} \text{ S cm}^{-1}$ was

achieved at 80 °C for the optimal composition (PEO)₃₀/KBPh₄. This composition was also stable against metal electrodes up to 4 V vs K⁰ at 60 °C. In a symmetric solid-state cell using Prussian Blue electrodes, the SPE demonstrated reversible K⁺ intercalation with a capacity of up to 20 mAh g⁻¹ and a characteristic low-voltage curve maintained over 20 cycles. These findings, which reveal a strong correlation between structure and conductivity properties, support further exploration of fluorine-free polymer electrolytes for K-ion battery applications.

CONCLUSION

The development of a bio-battery has been successfully achieved using cucumber juice and sodium chloride (NaCl) as ion sources, with tapioca flour serving as the solid electrolyte matrix. The bio-battery utilizing cucumber juice with varying fermentation durations produced the highest electrical output at 48 hours of fermentation, yielding a current of 0.76 mA and a voltage of 0.695 V. Furthermore, the addition of NaCl at the fermentation optimum (48 hours) reached its peak performance at a mass of 1.5 grams, resulting in a current of 2.01 mA and a voltage of 0.704 V. This study demonstrates the potential of bio-batteries constructed from low-cost, readily available materials through a simple fabrication method, indicating strong prospects for further development and practical applications.

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