논문 No.	Journal Title	First Author	Corresponding Author	Organization
TP-2-42	아이웨어 적용을 위한 플렉서블 멀티레이어 피부 건강상태 모니터링 플랫폼	송영환	김민구	인하대학교
TP-2-43	Ga2O3/Ti3C2Tx MXene 복합체 기반의 실온 암모니아 센서	차고은	박종성	경북대학교
TP-2-44	Development of a detection sensor based on lateral flow immunoassay for monitoring vancomycin in whole blood	정유경	양성	광주과학기술원
TP-2-45	Electrically tunable superradiant plasmonic nanocomposite	김현민	정현호	광주과학기술원
TP-2-46	Active Chiral Plasmonic Metasurface	김주환	정현호	광주과학기술원
TP-2-47	Research on Improving Fiber-Type Energy Storage Devices for Wearable Devices	이수범	안건형	경상국립대학교
TP-2-48	Fabrication of On-chip Microsupercapacitors based on Laser Lithography Process	권순근	안준형	한국기계연구원
TP-2-49	All Nanofibrous Triboelectric Nanogenerator-Based Self-Powered Pressure Sensor	Omar Faruk	박재영	광운대학교
TP-2-50	Enhanced Underwater Mechanical Sensing Using a Flexible Triboelectric Nanogenerator: A Combination of PVDF/Zn-Cr Layered Double Hydroxide Polymer Composite and Nylon 11 Nanofibers	비스와짓마한티	이동원	전남대학교
TP-2-51	차량 진동에너지 수확을 위한 코일진동형 전자기유도 에너지 하베스터	권대성	김현수	현대자동차
TP-2-52	불규칙 곡률반경 및 물체 형상 감지를 위한 프린팅 기반 소프트 압력센서 어레이	장재환	김민구	인하대학교
TP-2-53	다양한 형태의 감각기반 유저 인터페이스를 이용한 유아의 행동 패턴 감지 및 발달 특성 분석	이상민	김민구	인하대학교
TP-2-54	Development of a Soft and Flexible Wearable Temperature Sensor based on a Temperature-sensitive Composite Mixed with NiO Nanoparticles and C-PDMS	박세영	서민호	부산대학교
TP-2-55	Direct Writing Liquid Metal Inverse Patterning on Paper	김우찬	김대영	명지대학교
TP-2-56	Development of a mesh-type flexible electrode array for parallel recording of electrophysiological signals and fluorescence images	은종희	추남선	한국뇌연구원
TP-2-57	Enhanced Backflow Prevention in Microfluidic Check Valve through 3D Dome-shaped Valve Disk	마운호	황용하	고려대학교학과
TP-2-58	잉크젯 공정과 반응성 은 잉크를 활용한 면직물 기반 전극 제작 및 웨어러블 디바이스로의 활용	허보웅	김종백	연세대학교
TP-2-59	Biologically-inspired microlens array camera for ultrafast and low-light imaging	김현경	정기훈	한국과학기술원

Poster Session 3 (FP-3)

3월 29일 금요일
08:50~10:20

논문 No.	Journal Title	First Author	Corresponding Author	Organization
FP-3-01	이중 열분해 공정을 이용한 고재현성 공중부유형 탄소 1D 나노 구조체 제조 기법	곽종현	신흥주	울산과학기술원
FP-3-02	Piezoelectric micro-jet devices with interdigitated electrode system	허근영	이병철	한국과학기술연구원
FP-3-03	롤투롤 인쇄된 유연 플라즈모닉 메타표면	마지영	정현호	광주과학기술원
FP-3-04	Ice mold-assisted bidirectional freeze-casting of patterned aerogels for highly ordered porous structures	훠디엔홍	최정욱	중앙대학교
FP-3-05	Cyclic Olefin Copolymer(COC)기반의 유연하고 투명한 신경 전극 어레이의 제작	서윤	정준수	부산대학교
FP-3-06	전력반도체 모듈 역설계 및 고장 분석을 위한 실리콘 젤 제거	이규석	마병진	한국전자기술연구원

Enhanced Underwater Mechanical Sensing Using a Flexible Triboelectric Nanogenerator: A Combination of PVDF/Zn-Cr Layered Double Hydroxide Polymer Composite and Nylon 11 Nanofibers

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유연한 마찰전기 나노발전기를 이용한 수중 기계적 감지 향상: PVDF/Zn-Cr 층상 이중수산화물 고분자 복합재와 나일론 11 나노섬유의 조합

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Abstract

Underwater communication is a critical and challenging issue due to the complex nature of the underwater environment. The present study proposes an underwater wireless communication approach that relies on Maxwell's displacement current generated by a novel flexible triboelectric nanogenerator (TENG). We developed Zn–Cr layered double hydroxide (LDH) nanosheets interfaced with poly(vinylidene fluoride) (PVDF) and Nylon 11 nanofiber-based triboelectric nanogenerator (PN-TENG). The fabricated PN-TENG shows greatly enhanced output performance with an open circuit output voltage (V_{oc}), short circuit current (I_{sc}), and instantaneous power density (P) of 187 V, 40 µA, and 6.6 W m^{-2}, respectively. The operation of more than 20 red LEDs without any subsidiary batteries is demonstrated using the PN-TENG. Furthermore, the fabricated flexible devices showcase their potential for widespread application in self-powered wearable sensors capable of capturing various human motion activities. More importantly, the wirelessly received signals can trigger the operation of some electronics in real time.

Keywords: ***Triboelectric nanogenerator, underwater wireless communication, PVDF, Zn-Cr layered double hydroxide, self-powered***

1. Introduction

In the booming field of ocean exploration, underwater equipment and technology are attracting more and more attention [1]. In particular, obtaining underwater wireless communication has always been a critical challenge. Current underwater communication is achieved through different physical fields, such as the acoustic field, optical field, and electromagnetic field. However, all of these methods have numerous challenges and difficulties [2]. To overcome these challenges, alternative communication techniques are investigated through the displacement current, corresponding to $J_D = \partial D/\partial t = \varepsilon_0 \partial E/\partial t + \partial P/\partial t$ in the Maxwell's equation [3]. The first term of the displacement current i.e. $\partial E/\partial t$ induces electromagnetic waves used in information technology, especially in wireless communications whereas the second term $\partial P/\partial t$ induces the polarization of material [3]. In the previous work published by Prof. Z. L. Wang that the second term $\partial P/\partial t$ in the Maxwell's displacement current is directly related to the output electric current of the nanogenerators [3]. Few works have been presented on energy transmission or communications in air based on the displacement current generated by the triboelectric nanogenerator [4]. Compared to air, water has a larger dielectric constant, which is more conducive to the propagation of the polarization electric field. Therefore, based on the second term of the displacement current, i.e., the polarization electric field, underwater communication in complex waters is feasible. In this system, triboelectrically generated current creates a polarizing electric field underwater, which is transmitted from one electrode to another electrode. However, the low sensitivity of the triboelectric nanogenerator (TENG) limits its wide application.

To improve the sensitivity and performance of the TENG, Zn-Cr LDH nanosheets were incorporated into PVDF polymer to fabricate PVDF-Zn-Cr LDH nanofibers, which act as strong tribo-negative materials, while Nylon 11 nanofibers are used as strong tribo-positive materials to fabricate PN-TENG. The as prepared PN-TENG exhibited not only superior throughputs (V_{oc}~187 V, I_{sc}~40 µA, and power density~6.6 W m^{-2}) but also was used as a self-powered wearable sensor for detecting biomechanical signals for human health care monitoring. Furthermore, the feasibility of a real-life application for wireless underwater transmission was investigated under different salinity and obstacle conditions. Finally, the wireless received signals can drive more than 20 red commercial LEDs directly without using any energy storage systems.

2. Experimental section

2.1 Materials: Poly(vinylidenefluoride) (PVDF) pellets, Zinc nitrate ($Zn(NO_3)_2$), chromium nitrate ($Cr(NO_3)_3$), sodium hydroxide (NaOH), sodium tungstate (Na_2WO_4), Nylon 11, nitric acid (HNO_3), N, N-dimethylformamide (DMF), formic acid, dichloromethane and acetone were obtained from Sigma–Aldrich Korea Co., Ltd., South Korea, and Ni-Cu coated polyester fabric electrodes were purchased from Solueta Co. Ltd, South Korea. All the chemicals are analytical reagent grade and used without any further purification.

2.2 Preparation of pure PVDF and composite nanofibers and Nylon 11 nanofibers:

The preparation process and other controlling parameters were carried out as per our previous work [5]. To prepare the spinning solutions, 12 wt% PVDF was first dissolved in a mixed solvent of DMF and acetone (6:4) and stirred for 4 hours at 60°C. Subsequently, Zn-Cr LDH powder with 5 wt% was added to the PVDF solution and vigorously stirred for 8 hours at 60°C. For the preparation of Nylon 11 nanofibers, 10 wt% of Nylon 11 was dissolved in a mixed solvent of formic acid and dichloromethane (1:1) and stirred for 4 hours at 40°C. The electrospinning solution was then transferred into a 10 mL hypertonic syringe with a diameter of 0.8 mm to initiate the electrospinning process.

3. Results and discussion

The solution preparation process and methodologies employed for synthesizing pure PVDF nanofibers, and 5 wt% Zn-Cr LDH nanoparticles-incorporated PVDF (PVDF/Zn-Cr LDH) nanocomposite nanofibers are explained in detail in the experimental section. The FE-SEM images of the as-prepared pure PVDF nanofibers and Zn-Cr LDH embedded PVDF composite nanofibers revealed a smooth surface (Fig. 1a,b). The average diameter of the as-prepared PVDF/Zn-Cr LDH nanofibers is reduced in comparison to pure PVDF nanofibers. A reduction in the diameter of the PVDF/Zn-Cr LDH nanocomposite nanofibers is attributed to the increased total charge originating from the LDH nanosheets enhancing the exerted force in the electrospinning jet and reducing the fiber diameter. The XRD pattern of pure PVDF and its LDH composite nanofibers are presented in Fig. 1c. The comparison of energy harvesting performance of pure PVDF/Nylon 11 and PN-TENG is shown in Fig. 1d,e. The open-circuit output voltage (V_{oc}) and short-circuit current (I_{sc}) of the pure PVDF/Nylon 11 TENG was found to be 30 V and 10 μA, respectively, under an iterative hand imparting pressure (Fig. 1d,e). The PN-TENG generated a V_{oc} of ~187 V and I_{sc} of ~40 μA (Fig. 1d,e). The reason for the higher electrical output may be that the PVDF/Zn-Cr LDH nanofibers possess a higher β-phase content, and longitudinal piezoelectric coefficient (d_{33}) compared to the pure PVDF nanofibers. Furthermore, the instantaneous voltage drop (V_L) and power density (P) of the PN-TENG was measured under a hand imparting pressure while varying the external load resistance (R_L) (Fig. 1f). The power density of the PN-TENG was estimated using the formula $P = \frac{{V_L}^2}{A.R_L}$, where A is the effective surface area and V_L is the voltage drop across the load resistance R_L. The estimated maximum power density and corresponding load resistance were 6.6 W m^{-2} and $R_L \approx$ 119 MΩ, respectively. This suggests that 119 MΩ is the resistance at which the maximum power was delivered, and impedance was perfectly matched. The superior instantaneous power density of the PN-TENG was sufficient to turn on more than 20 commercial light-emitting diodes (LEDs) without the need for any external storage system (right lower inset of Fig. 1f).

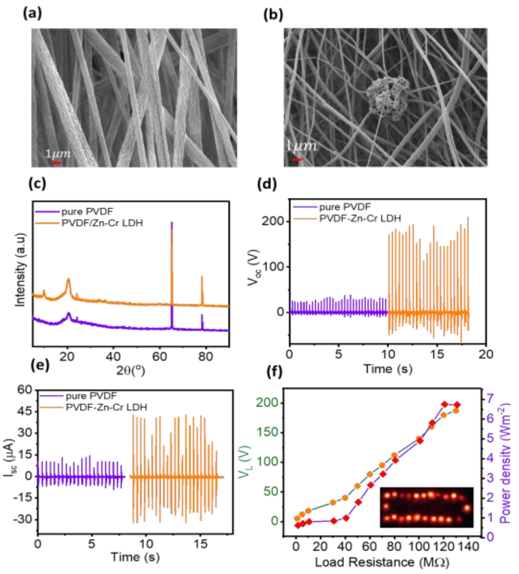

Fig. 1. (a,b) Showing the FE-SEM images of the pure PVDF and its composite nanofibers respectively. (c) XRD pattern of pure PVDF and its composite nanofibers. Triboelectric energy harvesting. (d) V_{oc}, and (e) I_{sc} of pure PVDF and its composite based TENG. (f) Variation in the output voltage and power density of the PN-TENG with external load resistances.

4. Conclusion.

In summary, we successfully fabricated the PVDF/Zn-Cr LDH nanocomposite and Nylon 11 nanofibers based TENG (PN-TENG) which exhibited superior performance (V_{oc}~187 V, I_{sc}~40 μA, and power density~6.6 W m^{-2}). Finally, the device is capable of transferring signals wirelessly in underwater effectively.

Acknowledgments

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