

## G2B : 에너지 환경 세라믹스

### G2B-1 | An Eco-friendly 2D-Layered MA<sub>3</sub>Bi<sub>2</sub>I<sub>9</sub> perovskite for High-power Hybrid Nanogenerator and storage device

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With a growing focus on wearable, portable, and wireless electronic devices, the demand for sustainable and portable electrical power sources is continuously increasing [1]. To address the limitations of batteries, researchers have developed various harvesters capable of converting ambient energies, such as solar, thermal, and mechanical energy, into electrical power [2]. Mechanical energy, in particular, represents a significant source of wasted energy, and it can be harnessed using piezoelectric nanogenerators (PENGs), triboelectric nanogenerators (TENGs), and more. Among these nanogenerators, TENGs have gained significant attention due to their high output power and cost-effective fabrication routes [2,3]. The efficiency of TENG relies on various parameters, including material properties, surface treatment, and dielectric constants [3]. Halide perovskites (HPs) have recently emerged as promising materials for mechanical energy harvesting applications thanks to their decent dielectric and piezoelectric properties [4]. Moreover, recent studies have demonstrated that HP materials are suitable candidates for energy storage supplication [5]. For instance, a methylammonium tin halide perovskite-based self-charging power unit is demonstrated by the integration of MA<sub>2</sub>SnCl<sub>6</sub>-based PENG with MA<sub>2</sub>SnCl<sub>6</sub>-based lithium-ion battery (LIB) [6]. Hence, the exploration of novel lead-free and efficient HP materials for self-charging power units is highly desirable to enable the self-powered operation of wearable or portable electronics. Herein, we present the application of air-stable 2D-layered lead-free MA<sub>3</sub>Bi<sub>2</sub>I<sub>9</sub> (MA = CH<sub>3</sub>NH<sub>2</sub>) for stretchable hybrid nanogenerators and electrode materials in LIB. Initially, we constructed high-performance and stretchable hybrid nanogenerators based on the MBI perovskite, which was composited with SEBS polymer to harvest mechanical energy in both piezoelectric nanogenerator (PENG) and triboelectric nanogenerator (TENG) modes. By varying the perovskite addition, we controlled the dielectric polarization of the fabricated stretchable MBI-SEBS composite film, leading to gradually improved output performances in both PENG and TENG devices. The highest performance was achieved at 12 wt% perovskite loading, where the 12

wt% TENG demonstrated an impressive output voltage of 537 V and a power density of 3.04 mW/cm<sup>2</sup>. The electrochemical performance of MA<sub>3</sub>Bi<sub>2</sub>I<sub>9</sub> as a cathode material with the Al<sub>2</sub>O<sub>3</sub> surface coating was investigated and exhibited high specific capacity and long-term stability. Furthermore, we investigated the electrochemical performance of MA<sub>3</sub>Bi<sub>2</sub>I<sub>9</sub> as a cathode material with Al<sub>2</sub>O<sub>3</sub> surface coating, revealing high specific capacity and long-term stability. Subsequently, we utilized the developed hybrid nanogenerator to charge the MA<sub>3</sub>Bi<sub>2</sub>I<sub>9</sub>-based lithium-ion battery. The charged LIB from the TENG successfully powered small-scale electronic devices, including a smartwatch and a calculator.

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### G2B-2 | 단결정 기반 (K,Na)NbO<sub>3</sub>/CuO 마이크로/나노 이중계면 압전촉매 개발

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Developing high-performance photo-piezocatalytic activity in single-crystal-based heterostructured ferroelectrics is a compelling goal, driven by the desire for significant piezo-potentials and more reactive charges capable of initiating desired redox reactions. To this end, we present a novel approach wherein a heterostructure consisting of (K,Na)NbO<sub>3</sub> (KNN) microcuboids and CuO nanodots on a single-crystal platform is designed. This heterostructure exhibits enhanced photo-piezocatalytic activity and is fabricated using a facile strategy that capitalizes on the synergistic interplay between heterojunction formation and the single-crystal-based piezoelectric effect. The catalytic performance of the KNN/CuO heterostructure in degrading rhodamine B was studied under various stimulation conditions: exposure to light irradiation, ultrasonication, or concurrent application of both stimuli. In comparison to polycrystalline KNN powders and untreated single-crystal KNN counterparts, the single-crystal-based KNN/CuO configuration displayed

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elevated piezo-current density and an optimally aligned energy-band structure. As a result, it demonstrated 5.23 and 2.37 times greater piezocatalytic degradation activity for rhodamine B, respectively. This study provides valuable insights into the intricate relationships among heterojunctions, piezoelectric responses, and catalytic mechanisms in the context of single-crystal-based heterostructured catalysts.

### G2B-3 | ZnO-PTFE Composite Films for Antimicrobial Display Coating and High-sensitivity Touch Sensor Applications

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Sensors have recently received substantial consideration owing to the rapid growth of the Internet of Things (IoT) for the real-time monitoring of environs and humanoid actions. Predominantly, newly exposed nanogenerator-based self-powered sensors are potential entrants to overcome the current problems of conventional sensors, including regular monitoring, the lifetime of a power unit, and portability. Besides, environmental contamination by microorganisms is a major cause of the transmission of several infectious diseases. Interactive touch-based devices including displays and touch sensors are known to be hotspots for pathogenic microorganisms, from where they spread onto the human body through contact. Therefore, antibacterial touch sensors play an important role in reducing contamination by microorganisms. Recently, metal and metal oxide nanomaterial-based coatings including Ag, Cu, ZnO, TiO<sub>2</sub>, etc have received greater attention because of their superior antibacterial activities. In particular, ZnO thin films are known to exhibit excellent antimicrobial properties. However, the high refractive index value of ZnO material impedes its practical application as an anti-reflective coating for touch-screen displays. Besides, polytetrafluoroethylene (PTFE) polymer has been widely implemented as a surface coating material for various displays, and medical devices owing to its beneficial features including corrosive resistance, self-cleaning, mechanically durable, water-repellent, and low refractive-index value. Therefore, fabricating ZnO-polymer composite thin film coatings at low temperatures with controllable parameters such as thickness, particle size, crystallinity, morphology, composition, etc., will be highly feasible for realizing the potential antibacterial and anti-reflective properties. In this study, the transparent zinc oxide and PTFE polymer (ZnO-PTFE) composite thin films are

grown on glass substrates at room temperature by co-sputtering ZnO and PTFE polymer targets. The ZnO-PTFE exhibits a significantly low refractive-index, high transmittance, and excellent hydrophobic properties, along with outstanding antibacterial activities of ~6.2 and ~4.7 for E. coli and S. aureus, respectively. Further, the ZnO-PTFE composite-based TENG is shown to provide a high triboelectric output voltage of ~224 V, a current density of ~21.4  $\mu$  A/cm<sup>2</sup>, and a power density of 1.65 mW/cm<sup>2</sup>. Furthermore, the linear response of the TENG to driven pressure indicates its excellent pressure-sensing ability, with an unprecedented sensitivity of 75.31 V/kPa and a touch sensitivity of 31.36 V/kPa. Further, the real-time application of ZnO-PTFE as a display coating and self-powered touch sensor is demonstrated.

### G2B-4 | Effect of triple doping on the thermoelectric properties and microstructure of GeTe-based thermoelectric materials

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Global warming and energy scarcity are increasing the demand for clean and sustainable energy sources. Therefore, many studies are being conducted on energy generation, conversion and storage. Thermoelectric conversion technology can convert heat into electricity using thermoelectric effects such as the Seebeck effect, the Peltier effect, and the Thomson effect. The performance of thermoelectric materials is evaluated by a dimensionless figure of merit,  $ZT = S^2\sigma T/\kappa$ , where S,  $\sigma$ , T and  $\kappa$  are the Seebeck coefficient, electrical conductivity, absolute temperature and thermal conductivity, respectively. A high power factor ( $S^2\sigma$ ) and low thermal conductivity are required to achieve a high figure of merit. GeTe-based thermoelectric materials are intermediate-temperature thermoelectric materials, and are compounds that undergo a phase transition from rhombohedral to cubic at about 430 °C. Pristine GeTe has a low Seebeck coefficient due to its high carrier concentration ( $\sim 10^{21}$  cm<sup>-3</sup>). Therefore, studies on increasing the figure of merit by changing the band structure, carrier concentration, microstructure, etc. have been reported. In this study, we simultaneously tried to optimise the carrier concentration, improve the Seebeck coefficient, and decrease the lattice thermal conductivity by triple doping. In addition, the triple-doped microstructure and phase transformation were investigated.

### G2B-5 | 격자 왜곡을 통한 고효율 산소 발생 촉매 표면 재건 유도 전략

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Systematic control of surface reconstruction during catalysis remains a challenging task. In particular, inducing a surface structure following the lattice oxygen mechanism (LOM), which significantly reduces the overpotential in oxygen evolution reaction (OER) catalysts, has not been well explored. Herein, we introduce anion-incorporated perovskite oxides F-LaNiO<sub>3</sub>. F-incorporation causes structural distortion in LaNiO<sub>3</sub>, which facilitates the lattice oxygen participation during OER, allowing self-induced surface reconstruction. This self-reconstructed surface favors the LOM pathway for OER, exhibiting superior performance comparable to state-of-the-art noble metal catalysts. This process is followed by self-termination through dynamic equilibrium, as revealed by post-mortem analysis. Our strategy provides valuable insights into self-induced LOM catalysis and has potential applications in OER catalyst design strategies.

### G2B-6 | Single-Atom Anchored Cation Defective NiFe-LDH for Water Electrolysis

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Layered double hydroxide (LDH) is deemed a promising catalyst for electrochemical applications because of its favorable adsorption/desorption energy and cost-effectiveness. NiFe-LDH, one of the LDHs, consists of positively charged host layers (brucite-like Ni(OH)<sub>6</sub> and Fe(OH)<sub>6</sub> octahedra) and interlayer anions such as sulfate, chloride, and nitrate. It has been studied as an excellent candidate for industrial applications of water splitting, particularly as a catalyst for both the anode and cathode reactions due to its bifunctional catalytic activity. However, despite its outstanding catalytic activity, it has shown poor long-term stability in alkaline media, due to the dissolution of iron.

The stability of the catalyst can significantly increase with the formation of cation vacancies by suppressing the dissolution of iron. For example, Peng et al. demonstrated enhanced stability through vacancy-rich NiFe-LDH obtained by alkaline etching of NiFeZnAl-LDH and more recently, Wu et al. proved that cation vacancies in NiFe-LDH are a motif of reconstruction. Although vacancy engineering has enhanced the stability and catalytic activity of NiFe-LDH, the activity is not sufficient for application in industrial fields.

We achieved higher catalytic activity performance by decorating single tungsten atoms onto the pre-formed cation vacancies of NiFe-LDH. The single tungsten atoms were deposited onto the vacancy-rich NiFe-LDH using the simple and mass-producible hydrothermal method. Tungsten ions preferentially deposited onto the cation vacancies due to their higher positive charge density. Through the synergistic effect of the tungsten single atom and lattice distorted NiFe-LDH, a highly active and durable catalyst was successfully synthesized.

### G2B-7 | High-performance interfacial solar steam generation of black TiO<sub>2-x</sub> with high-concentration bulk oxygen vacancies

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Interfacial solar steam generation (ISSG) using metal oxides has attracted significant attention regarding excellent durability and stability under extreme environmental conditions than typical carbon-based ISSG. While black TiO<sub>2-x</sub> nanoparticle (NPs) have emerged as promising photothermal material due to their outstanding light absorption properties, they suffer from low evaporation rate (0.8-1.53 kg m<sup>-2</sup> h<sup>-1</sup>). Therefore, it remains a significant challenge to further improve photothermal properties of black TiO<sub>2-x</sub> NPs for high-performance and reliable ISSG. Herein, we achieved an outstanding evaporation rate of black TiO<sub>2-x</sub> NPs higher than carbon black, which is a typical carbonaceous photothermal material. Moreover, it demonstrated that the high-concentration bulk oxygen vacancies promote photo-to-heat conversion by the recombination of photo-excited charge carriers. In this work, a novel synthesis process is also proposed to introduce high-concentration bulk oxygen vacancies within the TiO<sub>2</sub> lattice, overcoming the limitation of the conventional reduction-based synthesis processes that lead to surface concentrated oxygen vacancies.

### G2B-8 | High response, Self-powered and Flexible UV Sensor based on Zn-Al:LDH Ns/NiO/Spiro-MeOTAD Heterojunction

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Self-powered ultraviolet (UV) photodetectors with high photo response and good flexibility have attracted extensive interest in various fields, including image sensing, environmental monitoring and Internet of

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Things (IoT). Several materials including semiconductors, and organic materials are currently being investigated for detecting the level of harmful UV radiation in the atmosphere. The next generation UV sensors demand new eco-friendly functional materials that are easy to fabricate, self-powered, stable and cost effective. Layered double hydroxides, an emerging class of anionic clay with lamellar structure, have attained considerable attention in the field of material science due to their unique thermal, optical and dielectric properties. However, the synthesis of LDH nanostructures is not only a complicated method using a lot of chemicals but also is a time taking process. In addition, there have been no or few reports on LDH based UV photodetectors so far. Herein, we report an eco-friendly, self-powered and flexible UV detector based on vertically oriented Zn-Al: LDH nanosheets. The nanosheets have been facilely prepared by facial target sputtering of 10% Al doped ZnO at room temperature and dipping the as prepared AZO film in deionized water. This is followed by the sputtering deposition of p-NiO thin film on LDH Ns. The gaps in Zn-Al:LDH-NiO network is filled with Spiro-MeOTAD organic polymer and finally, the top gold electrode is deposited. The UV sensing behavior of the device is confirmed by studying the IV and I-t characteristics at different UV intensity levels. Moreover, the devices show stable performance after several bending cycles.

### G2B-9 | Metal Oxide Materials for Perovskite Solar Cells

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Perovskite solar cells (PSCs) have received much attention due to their impressive power conversion efficiencies (PCEs) surpassing 26%. However, they still suffer from issues such as stability and efficiency, which are significant hurdles to their commercialization. Notably, metal oxide nanomaterials as the electron-transporting layer (ETL) plays a pivotal role in addressing these issues, as their morphology and surface defect directly impact the stability and efficiency of these devices. Therefore, it is imperative to focus on the development of metal oxide nanomaterials for use as ETLs in order to enhance the efficiency and stability of PSCs. In this presentation, I will talk about the synthesis and practical application of these metal oxide nanomaterials as ETLs for PSCs. Furthermore, I will discuss strategies for managing defects with the aim of further enhancing the efficiency and stability of these

devices. Lastly, recent research will be briefly introduced.

### G2B-10 | Nanostructured Functional Inorganic Materials for Perovskite Optoelectronics

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The power conversion efficiency (PCE) of perovskite solar cells (PSCs) has been renewed annually, now recorded to 26.1%, which is the highest efficiency for thin-film solar cells, raising expectations for commercialization. However, the PSCs have a massive technical lack in entering the photovoltaic industry because of the low PCE of perovskite solar modules (PSMs), poor stability, high levelized cost of energy (LCOE), and environmental issues. This lecture is dealing with our efforts to facilitate the commercialization of perovskite solar cells. First, the reduction of the efficiency gap between small-area PSCs and large-area PSMs via the solution process is discussed. Second, the environmental issues for manufacturing and sustainable use of PSMs are dealt with, and it is demonstrated that the recycling/reuse of PSMs is the most promising way to reduce manufacturing costs.

### G2B-11 | Buried Interface Modulation via PEDOT:PSS Ionic Exchange for the Sn-Pb Mixed Perovskite Based Solar Cells

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To apply Sn-Pb mixed perovskite solar cells (PSCs) for highly efficient single- or multi-junction devices, understanding device-specific buried interfaces is necessary. Poly [3,4-ethylenedioxythiophene]: poly[styrene sulfonate] (PEDOT:PSS) is primarily used as a hole transport layer in Sn-Pb mixed PSCs. However, the spatial heterogeneity of PEDOT:PSS, caused by its PEDOT-rich and PSS-rich domains, induces many defects at the buried interface in PEDOT:PSS/perovskite, which limits device performance. This study introduces an effective ionic exchange for PEDOT:PSS surface modification to drastically enhance the interfacial properties between PEDOT:PSS and perovskite. The surface modified PEDOT:PSS by ionic exchange brought the conformal interfacial contact and enhanced charge extraction confirmed via TRPL analysis. As a result, we achieved more than 21% efficiency of p-i-n structured Sn-Pb mixed PSCs. In addition, we confirmed that this ionic exchange was also effective for tandem devices. In conclusion, we fabricated all-perovskite tandem solar

cells with an approaching 24% efficiency through this ionic exchange.

### G2B-12 | Reducing Defect Density of Wide Bandgap Perovskite Solar Cells by Grain Boundary Patching for High Efficient Monolithic All-Perovskite Tandem Solar Cells

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Mixed halide based wide bandgap (WBG) perovskite solar cells (PSCs) are important for monolithic tandem solar cells. Nevertheless, front WBG sub-cell (>1.8 eV) perovskite solar cells suffer from large open-circuit voltage ( $V_{OC}$ ) deficits due to high defect density and unwanted halide segregation under light illumination. The large  $V_{OC}$  deficit of WBG perovskite compositions limits the overall tandem device performance. One of the main reasons for  $V_{OC}$  deficit in WBG cells is grain boundary defects in the polycrystalline perovskite films. Consequently, reducing and passivating grain boundary defects is essential for achieving high  $V_{OC}$  and producing WBG PSCs. Our findings suggest that forming inorganic based 2D-perovskite at grain boundaries by adding additives into perovskite precursor solution can greatly reduce the defects of WBG perovskite films, hence enhancing their operational efficiency and stability. Therefore, we fabricated WBG solar cell device with a bandgap 1.82eV,  $V_{OC}$  of 1.28V and power conversion efficiency(PCE) of 18.02% and confirmed that combining these high  $V_{OC}$  producing WBG cells with narrow bandgap perovskite cells result in high performance tandem solar cells.

### G2B-13 | High Performance Inorganic CsPbI<sub>2</sub>Br Perovskite Solar Cells for Semi-Transparent Photovoltaic Applications

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Inorganic CsPbI<sub>2</sub>Br perovskite has a substantial potential for semi-transparent solar cells, however it exhibits relative instability in the air as well as significantly lower efficiency than the theoretical efficiency limit. To further enhance the air-stability and efficiency of CsPbI<sub>2</sub>Br-based perovskite solar cells (PSCs), it is crucial to improve the crystallinity and passivate the defects within films that accelerate the phase transformation to the photo-inactive phase in the air. Here, we reported that

crystallization management via incorporating sodium formate (NaFo) in a CsPbI<sub>2</sub>Br effectively leads to enlarged grain size and reduced trap density. As a result, the device shows an improved power conversion efficiency (PCE) of 17.7% and retains over 95% of its initial PCE for 1000 hours. In addition, we introduced nickel oxide (NiOx) to fabricate the all-layer-inorganic PSCs exhibiting an efficiency of 16.6% and extend this approach into semi-transparent devices with sputtering for tin-doped indium oxide (ITO).

### G2B-14 | All-Inorganic Bismuth-Based Perovskite-Inspired Materials for Stable, High-Performance, and Self-Powered Photodetectors Embedded with CVD

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Organic-inorganic lead-based halide perovskites have attracted tremendous attention in optoelectronic and photovoltaic fields due to their excellent properties. However, the toxicity of lead (Pb) and the instability of the organic cation group hinder their future large-scale market development. To address these challenges, numerous low-toxic substitutes have been reported. Among them, lead-free ternary bismuth-halide-based perovskites A<sub>3</sub>Bi<sub>2</sub>X<sub>9</sub> have been identified as a promising candidate for eco-friendly and stable lead-free perovskite-inspired materials (PIMs). Moreover, all-inorganic perovskites are promising for photodetectors owing to their potentially superior tolerance to environmental factors, as compared with their hybrid organic-inorganic counterparts. This study demonstrates the representative of Cs<sub>3</sub>Bi<sub>2</sub>I<sub>9</sub> (CBI) film, which shows the outstanding properties of good crystallinity, smooth and compact morphology perovskite films via the chemical vapor deposition (CVD) approach. Under 382 nm illumination, the CBI-fabricated photodetectors demonstrated the self-powered operation (zero bias) with a high responsivity of 1.57 A/W, and high specific detectivity of  $3.38 \times 10^{13}$  Jones. Furthermore, the CBI-intrinsic films showed exceptional moisture stability and negligible change after 100 days of storage in ambient conditions. These photodetectors devices exhibited excellent long-term operational stability with 2% degradation of their photocurrent under UV illumination at 1 mW/cm<sup>2</sup> for 500 h owing to the exceptional stability of the core perovskite film. This study thus highlights the important role of all-inorganic perovskite in the development of high-performance lead-free perovskite-inspired optoelectronics toward self-powered, stable, and non-toxic.