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A Greener and Functional Antisolvent for the Fabrication of Perovskite Solar Cells

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조재민

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Abstract

Organometal trihalide perovskite has recently been considered as one of the leading candidates to achieve highly efficient perovskite solar cells. However, current PSC procedures commonly rely on large volume of highly toxic halogenated solvents or highly flammable solvents which are not favorable for large-scale commercialization of PSCs.

Thus, finding greener solvents for the fabrication of perovskite solar cells is important to improve sustainability and reduce health risks. Herein, the research employs non-toxic and nonhalogenated salicylaldehyde as an antisolvent and posttreatment dissolving solvent. Salicylaldehyde is utilized as a nonreactive, flame resistive and health-risk-free anti-solvent that can be extracted from the buckwheat, guaranteeing safety in the fabrication process. Moreover, this solvent has a semipolar characteristic due to the hydroxyl group (-OH) attached to a benzene ring, enabling it to dissolve passivation agents.

As a result, the perovskite solar cell using green solvent achieved comparable power conversion efficiency to conventional hazard solvents. Moreover, encapsulated devices retained over 80% of their initial power conversion efficiency, after ~750 h of constant 1-sun illumination, and after ~1100 h under 60 °C heat. Overall, this work demonstrates that semipolar salicylaldehyde can be a safer alternative solvent for environmentally friendly fabrication in the perovskite solar cell process.

Keyword : perovskite solar cells, salicylaldehyde, green solvents, light stability, heat stability. Student Number : 2020-29315

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Chapter1.

Overview of Perovskite Photovoltaics

1.1. Operation Mechanism of Solar Cells

The solar cell is low-cost and promising approach to generating electricity since it converts light energy into electricity. The solar cell is made by a p-n junction of p- and n-doped semiconductor material. As shown in Fig. 1-1, the photovoltaic energy conversion in solar cells consists of two steps [1,2]. Firstly, the phonon absorbed in the material produces hole and electron pairs. The hole and electron are separated by charge transport layer material which collects and transport the charges generated from a light absorbing material. The potential difference between the anode and the cathode generates a current thus generating electrical power.

Usually, three parameters, short-circuit current (J_{sc}), open-circuit voltage (V_{oc}) and fill factor (FF), are considered to characterize the performance of solar cells (as presented in Fig. 1-2) [3,4]. The power conversion efficiency (PCE), defined as the ratio of between the maximum power output of the solar cell, and calculated by $J_{sc} \times V_{oc} \times FF$. Generally, semiconductors with lower bandgap have high J_{sc} , since light-harvesting material absorbs much of incident light. Whereas semiconductors with higher bandgap have high V_{oc} , due to higher potential difference made by light-harvesting material. The tradeoff between J_{sc} and V_{oc} creates the theoretical limit of solar cell and defined as Shockley-Queisser limit (presented in Fig.1-3) [5]. Therefore, light harvesting material's bandgap should be optimized, and the bandgap between 1.2~1.5 eV is favorable to exhibit high PCE.



Fig. 1-1. Energy-band diagram of a *p-n* junction solar cell. From Ref. [1].



Fig. 1-2. J-V curve to evaluate the cells performance. From Ref. [4].



Fig. 1-3. Record efficiency of solar cells of different materials against their bandgap, in comparison to the Shockley-Queisser limit. From Ref. [5].

1.2. Advantages of Perovskite in Field of Solar Cell

Organometal-halide perovskites have become especially attractive both in the field of solar cells due to the rapid boost of PCE from the initial 3.8% to over 25% within 10 years [6-8], very cheap production cost, superior intrinsic properties such as high absorption coefficient [9] and tunable band gap [10].

Organometal-halide perovskites with a formula of ABX_3 (shown in Fig.1-4) where *A* site is methylammonium (MA), formamidinium (FA), or Cesium, *B* site is Pb²⁺, Sn²⁺, Ge²⁺, and *X* site is halide anion such as I⁻, Br⁻, Cl⁻ [6-8,11,13]. Presented in Fig. 1-5, changing the composition engineering of the *ABX*₃ enables perovskite solar cells to tune band gaps in the region of 1.17~3.10 eV [10,12].

Since the perovskite layer is easily deposited through solution or vacuum fabrication methods, perovskite solar cells have great potential to reduce costs [14]. Moreover, perovskite solar cell with low-temperature solution methods exhibits relatively high stability. This low-temperature solution process enables perovskite solar cells to be fabricated with various structures, such as n-i-p mesoscopic, n-i-p planner, or p-i-n planar structure (as demonstrated in Fig. 1-6) with high PCE [13]. These characteristics, tunable band gaps with various device structures, makes perovskite solar cell preferable to combining with other types of solar cells to form tandem solar cell structures.



Fig. 1-4. Crystal structure of perovskite materials. Form Ref. [13].



Fig. 1-5. Bandgap tuning of perovskite by composition engineering. From Ref. [10].



Fig. 1-6. Different device structures of perovskite solar cell. From Ref. [13].

1.3. Fabrication of Perovskite Layer

Various techniques to optimize the morphology of perovskite films were studied to fabricate high-quality perovskite films. Two-step sequential method [15-18], vapor assisted solution process [19,20] and antisolvent-assisted crystallization [21-24] method have been proposed (as presented in Fig. 1-7). So far, the antisolventassisted crystallization method has been an effective method for preparing highquality perovskite films. However, the antisolvent-assisted crystallization process inevitably produces perovskite films with high defect densities which originate from uncoordinated lead and halide ions at the grain boundaries and perovskite bulk [25-27]. Therefore, passivating the uncoordinated defects is an effective approach to improving the stability and PCE of perovskite solar cells.



Fig. 1-7. Methods to fabricate perovskite layer. (a) antisolvent-assisted crystallization, (b) two-step sequential method and (c) vapor assisted solution process. From Ref. [21,16,19].

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Chapter 2.

A Greener and Functional Antisolvent for the Fabrication of Perovskite Solar Cells

2.1. Introduction

On the large-scale commercialization aspect, the solvent process is commonly adopted in the Perovskite solar cells (PSCs) procedure. Under ambient conditions, the solvent process accompanies solvent exposure, arising safety and health issues. Conventionally, chlorobenzene (CB) and diethyl ether (DE) are extensively used in the antisolvent-assisted crystallization method [1-3]. However, CB can cause severe health issues, since CB is a highly toxic, halogenated solvent that is carcinogenic. DE is a highly flammable solvent that has a boiling point of 34.5 °C, also DE can cause dizziness and drowsiness. Developing more environment-friendly solvents is essential to avoid hazards and health risks during the procedure. Recently, several green antisolvent including ethyl acetate, anisole, ethanol and methyl benzoate have been developed to prepare perovskite films with comparable PCEs [4-9]. However, several other hazard solvents are used in the PSCs fabrication process other than antisolvent. To create a safer fabrication process environment with less systematic risk, widening the solvent option is important.

The spin-coating method is commonly adopted in the passivation strategy, and passivating agents are dissolved in polar solvents, mostly isopropyl alcohol (IPA). However polar solvents inevitably dissolve the perovskite layer, thus semipolar solvents can be an alternative option for a passivation strategy to minimize perovskite layer damage. Salicylaldehyde (SAL) exhibits both polar and nonpolar characteristics since it has both hydroxyl (-OH) and phenyl group (-C₆H₅). Herein, the research utilizes SAL as a multi-functioning solvent for both anti- and post-treating solvents. Thus, SAL is used as an antisolvent to quench perovskite precursor and as a functional solvent to dissolve phenethyl ammonium iodide (PEAI) which is spin-coated as the passivation layer above the perovskite films.

Antisolvent and passivation steps are key for the high PCE device with high longterm stability [34,14]. Consequently, the solar cell made by this approach shows the highest PCE of 20.23%. The stability of the PSCs is also increased due to the decreased charge recombination trap sites and the cells keep >80% of their initial efficiency for >750 h under continuous 1-sun illumination and >1100 h under heat conditions (60 °C) with encapsulation.

2.2. Experimental Section/Methods

Substrate Preparation: The ITO patterned substrate (AMG) was sonicated for 15 min each in acetone, isopropyl alcohol and deionized water, followed by UV-O₃ treatment for 15 min. The tin (II) oxide (SnO₂) electron-transport layer (ETL) was deposited by spin-coating (3000 rpm for 30 s) SnO₂ nanoparticles (in H₂O, Alfa-Aesar) diluted in H₂O with a 1:4 volume ratio, and substrates were heated at 150 °C for 30 min on a hot plate. After the ITO/SnO₂ substrates were left to cool down to room temperature, the as-prepared substrates were UV-O₃ treated for 15 min before perovskite layer deposition.

Perovskite layer deposition using Green Solvent: The perovskite precursor solution was prepared by dissolving formamidinium iodide (1.60 M, FAI, Great Solar Laboratory), lead iodide (1.68 M, PbI₂, TCI Chemicals) and methylammonium chloride (0.48 M, MACl, Sigma-Aldrich) in a mixed solvent (6:1 volume ratio) of N,N-dimethylformamide (DMF, Sigma-Aldrich) and dimethylsulfoxide (DMSO, Sigma-Aldrich). The perovskite layer was deposited by spin-coating of the perovskite solutions at 1000 rpm for 30 s for the first step and 5000 rpm for 10 s for the second step. The SAL perovskite films were deposited by dropping salicylaldehyde (0.2 mL, Sigma-Aldrich) 7 s after the beginning of the second step as an antisolvent. The DE perovskite films were deposited by dropping diethyl ether (1 mL, Dae-Jung) 1 s after the beginning of the second step as an antisolvent. Then the substrates were annealed at 150 °C for 10 min in dry air. For the SAL:P films, phenethyl ammonium iodide (5 mM, PEAI; Great Solar Laboratory) was dissolved in salicylaldehyde (Sigma-Aldrich) and the solution (SAL: PEAI solution) was spin-coated on the substrates at 4000 rpm for 30 s. The SAL:P films were further annealed at 100 °C for 5 min to evaporate the residual solvent.

Hole transporting layer and Au top contact: The solution for the hole-transport layer (HTL) was prepared by dissolving spiro-OMeTAD (72.3 mg mL⁻¹, Lumtec) in 1 mL of chlorobenzene (Sigma-Aldrich) with the addition of 28.8 μ L of 4-*tert*-butylpyridine (*t*BP, SigmaAldrich), 17.5 μ L of bis(trifluoromethane) sulfonimide lithium salt (520 mg mL⁻¹, Li-TFSI, Sigma-Aldrich) solution in acetonitrile and 21.9 μ L of Co(II)-TFSI (384 mg mL⁻¹, FK209, Sigma-Aldrich) solution in acetonitrile as

additives. For the long-term device stability tests PTAA (20.0 mg, 33kDa; MS Solutions) in 1 mL of chlorobenzene (Sigma-Aldrich) with the addition of 6 μ L of 4-*tert*-butylpyridine (*t*BP; Sigma-Aldrich) and 4 μ L of bis(trifluoromethane)sulfonimide lithium salt (520 mg mL⁻¹, Li-TFSI; Sigma-Aldrich) solution. All HTL solution was spin-coated on the substrate at 3000 rpm for 30 s. Lastly, for the counter electrode, the Au electrode was thermally evaporated on the HTL. For the encapsulated device, UV curable epoxy resin (XNR-570, NAGASE) was used to seal the capping glass and an additional getter (AD Tech) was attached to the capping glass.

Characterization: Morphology of the perovskite films was characterized by the field-emission scanning electron microscope (Merlin Compact, Zeiss). The optical bandgap was analyzed by UV-visible absorption spectroscopy using a spectrophotometer (V-770, JASCO). Phases of the devices were examined by an X-ray diffractometer (New D-8 Advance, Bruker). For the steady-state and the time-resolved PL spectroscopy, the photoluminescence (PL) analyzer (FlouTime 300, PicoQuant) was utilized. In the analysis of the trap density of states, a potentiostat (Zive SP-1, WonATech) was used to obtain the impedance of the devices under zero bias and dark conditions. The device was examined with AC perturbation of 20 mV amplitude and frequency range from 10 MHz to 10 Hz. *J-V* curves and Steady-state current of the solar cells were measured by the impedance analyzer (CHI 604A, CH Instrument) under the illumination of the solar simulator (K-3000, McScience) for an active area of 0.09 cm². For the photostability test, encapsulated devices were tested by maximum-power-point tracking equipment (K3600, McScience) under continuous 1-sun illumination.

2.3. Results and Discussion

Fig. 2-1(a) illustrates the schematic of the SAL antisolvent assisted crystallization process along with SAL: PEAI passivation (SAL:P) process for preparing formamidinium lead triiodide (FAPbI₃) perovskite films under ambient air conditions. SAL is used as the antisolvent for the perovskite layer and the dissolving solvent of the passivation layer. During the spin coating process, SAL acts as nonpolar antisolvents inducing supersaturation of perovskite grains from perovskite precursors. In addition, SAL has a hydroxyl group (-OH) attached to a benzene ring as shown in Fig. 2-1(b), and this hydroxyl group makes SAL slightly polar. These dual properties make SAL miscible with organic compounds such as PEAI which is widely used as passivation agents, enabling the defect passivation process effective without damaging the perovskite layer [33,18].

The National Fire Protection Association (NFPA) 704 diamond, a standard system for identifying the hazards of materials, is used as an indicator of solvent safeness throughout the study [10]. Each division of NFPA 704 diamond is rated on a scale from 0 to 4 which stands for no hazard to severe hazard, and indicates the health, flammability and reactivity hazard of the materials. In this work, DE and IPA are used as control solvents since DE and IPA are mainly used as solvents for PSC fabrication [11-14]. SAL is an environmentally safe compound that can be extracted from buckwheat and is also used in the perfumery industry [15]. As shown in Figure 1b, NFPA 704 diamond shows that SAL is nonreactive, flame resistive and health risk-free compared to its counterpart. Moreover, the following experiment is shown as photographs in Fig. 2-2(a) to compare the flammability aspect of DE and SAL. The match on fire is dropped in 1 mL of SAL and DE. The vial with DE bursts into flame and lasted over 15 s, while the combustion did not occur in the vial with SAL.



Fig. 2-1. Fabrication schematic and structural formula and safeness indications of solvents. (a) Schematic presentation of the fabrication procedure of the perovskite active layer. (b) The structural formula and NFPA 704 diamond of diethyl ether, salicylaldehyde and isopropyl alcohol.



Fig. 2-2. Safety test of solvents and structural formula of phenethyl ammonium iodide. (a) The picture of the flammability test after a certain amount of time with 1 mL of DE and SAL. (b) The structural formula of PEAI.

Morphologies of FAPbI₃ perovskite films with DE, SAL and SAL:P are investigated to further study the effects of the green solvents on perovskite films. The cross-sectional and top-view scanning electron microscopy (SEM) images of perovskite films with different solvents are shown in Figs. 2-3(a) and (b). Calculated from SEM images, Fig. 2-3(c) presents the grain size distribution of DE, SAL and SAL:P films. As shown in Fig. 2-3(c), the average grain size of the SAL-based films (SAL, SAL:P ~1000 nm) increased compared to that of DE (~900 nm). The SEM images show that SAL can produce larger grain and comparable smooth films compared to conventional antisolvents. Wei Huang *et al.* demonstrated that antisolvent with a high boiling point induces secondary crystal growth during the thermal annealing process. Similarly, SAL, which has a higher boiling point (197.0 °C) compared to that of DE (34.5 °C), causes secondary crystal growth in the thermal annealing process and produces larger grain size perovskite films [5-8].

The UV-visible spectra shown in Fig. 2-3(d) imply that there is no significant difference in bandgap between solvents. To further investigate the difference induced by different solvents, time-resolved photoluminescence (TRPL) spectra are explored. TRPL decay implies the charge recombination and transport rate at the interfaces. The photoluminescence (PL) decay profile in Fig. 2-4 indicates the suppression of non-radiative recombination by the SAL:P strategy [17,18]. To further study charge transport characteristics at interfaces, TRPL spectra for the ITO/electron transporting layer (ETL)/perovskite/hole transporting layer (HTL) structure are obtained. As demonstrated in Fig. 2-3(e), the addition of the charge transfer layers accelerates the PL decay. The TRPL decay spectra are fitted biexponentially, and the averaged lifetimes of the carriers are obtained [16-19]. The fitted values of the a_1 , a_2 , τ_1 , τ_2 and calculated τ_{avg} of the PSCs are in Table 2-1. The τ_{avg} of the DE PSCs is 41 ± 1 ns while the SAL PSCs is 107 ± 10 ns, implying that the SAL PSCs have inferior charge transporting characteristics at the interfaces. However, the τ_{avg} of the SAL:P PSCs significantly decreased to 34 ± 6 ns. The TRPL decay suggests that defect passivation at interfaces mitigates the trap-assisted recombination and enhances charge extractions at the perovskite/HTL interface. The tendencies of the steady-state photoluminescence (SSPL) spectra from Fig. 2-3(d) match well with the TRPL spectra, reflecting the improved interface characteristic of perovskite/HTL and inhibited recombination in SAL:P PSCs.



Fig. 2-3. Morphological, optical properties of the perovskite films. (a) Crosssectional SEM images, (b) top-view SEM images and (c) grain size distribution of DE, SAL and SAL:P films. (d) UV-absorption of the perovskite films and steadystate photoluminescence (SSPL) spectra of DE, SAL and SAL:P devices. (e) Timeresolved photoluminescence (TRPL) spectra of DE, SAL and SAL:P devices.



Fig. 2-4. Time-resolved photoluminescence (TRPL) spectra obtained for glass/perovskite structure of DE, SAL and SAL:P.

	<i>a</i> ₁	τ ₁ [ns]	a2	$\tau_2^{}$ [ns]	$ au_{avg}$ [ns]
DE	$(2.95 \pm 0.37) x 10^3$	11.8 ± 0.8	$(3.9 \pm 0.24) x 10^2$	75.0 ± 3.2	40.7 ± 1.3
SAL	$(1.84 \pm 0.06) \times 10^3$	21.0 ± 0.6	$(1.6 \pm 0.08) \text{x} 10^2$	207.8 ± 13.3	106.5 ± 9.8
SAL:P	$(2.82 \pm 0.07) x 10^3$	15.7 ± 0.3	$(0.9 \pm 0.07) x 10^2$	114.5 ± 7.7	34.4 ± 5.7

 Table 2-1. Fitted and calculated parameter values from time-resolved

 photoluminescence of DE, SAL and SAL:P devices.

X-ray diffraction (XRD) pattern of perovskite films processed by different solvents is demonstrated in Fig. 2-5(a). While the diffraction pattern shows little crystallographic difference between SAL and DE, the peak at $2\theta = 12.7^{\circ}$ which is assigned to the (001) plane of photoinactive hexagonal PbI₂, shows a dramatic decrease in the case of SAL:P cases. This result suggests that SAL:P strategy successfully suppressed the decomposition of photoactive perovskite to photoinactive PbI₂, forming a perovskite film with a low surface defect density [34,35]. To analyze the lateral grain strain of PSCs, the Δk vs. *k* plot of different solvents obtained from the XRD pattern is demonstrated in Figs. 2-5(b-d). Δk is the full width at half maximum of each diffraction, $k = (4\pi/\lambda) \sin\theta$ is the scattering vector and local strain is extracted from the slopes of the linear fitting line. The resolution function is applied to correct the instrumental peak broadening in diffraction [20-22]. The value of local strain calculated from the XRD pattern is in order of SAL:P < DE < SAL, indicating that the SAL:P strategy can release residual strain at the perovskite/HTL interface.



Fig. 2-5. Device analysis of the perovskite solar cells. (a) XRD patterns of DE, SAL and SAL:P films. Δk vs. k plot of (b) DE, (c) SAL and (d) SAL:P films derived from XRD patterns.

To further investigate the origin of the enhanced characteristics at the interface, impedance analysis is used to explore the surface defect density of the PSCs. Impedance analysis reveals the capacitance feature of PSCs and electronic traps at the interfaces, discussed in previous reports [23-27]. The capacitance-frequency spectra are shown in Fig. 2-6(a) and Fig. 2-6(b) shows the trap distribution spectra obtained by taking the derivative of the capacitance. Compared to the DE PSCs, the SAL PSCs shows higher trap densities in the deep region. However, SAL:P PSCs show a dramatic reduction in trap densities at both shallow and deep level regions. The trap sites act as a recombination site of photocarrier, deteriorating the PSCs' device performance and device stability properties. Based on the results from the impedance analysis and PL spectra, SAL:P PSCs showed a reduction in both trap density and charge recombination rate at the perovskite/HTL interface.

Based on the improved features, the photovoltaic performance of PSCs is tested. *J-V* curves of PSCs under AM 1.5 G illumination from different solvents are plotted in Fig. 2-6(c) and Fig. 2-7. Photovoltaic parameters of the multiple solar cells are shown in Fig. 2-8. Benefiting from passivation effects the device performance of the SAL:P PSCs was higher than those of SAL and DE. The champion cell with SAL:P PSCs reached 20.23% with fill factor (FF) of 0.79 and open-circuit voltage (V_{oc}) of 1.02 V. In contrast, the PCE of SAL, DE PSCs were 17.97% and 19.39%, respectively. The device's FF and V_{oc} improvement was observed in SAL:P PSCs. Steady-state currents of the PSCs under maximum power voltage are presented in Fig. 2-6(d), where the SAL:P PSCs exhibit a stable current up to 400 s. Results from the previous research studies on the passivation of perovskite/HTL interface suggest organic amido group passivate uncoordinated lead ion defects which act as nonradiative recombination centers [34,35]. The high V_{oc} of SAL:P PSCs presumably suggests a reduction of the nonradiative recombination center by SAL:P strategy, resulting in increased photovoltaic performance.



Fig. 2-6. Photovoltaic performance of the perovskite solar cells. (a) Capacitancefrequency plot and (b) trap distribution spectra of DE, SAL and SAL:P devices. (c) *J-V* curves and (d) steady-state current of DE, SAL and SAL:P devices.



Fig. 2-7. *J-V* characteristics of perovskite solar cells for each solvent under forward and reverse scanning directions. *J-V* characteristics of (a) DE, (b) SAL and (c) SAL:P devices.



Fig. 2-8. Power conversion efficiency (PCE), fill factor, short circuit current (J_{sc}) and open-circuit voltage (V_{oc}) of DE, SAL and SAL:P devices.

For the device stability test, PTAA has been utilized as HTL, because PTAA has a polymeric structure that is more durable to heat and light stress than spiro-OMeTAD [28-30]. For the thermal stability test, encapsulated devices have been stored under 60 °C, ambient air condition. As illustrated in Fig. 2-9(a), the PCE of the SAL:P device retained over 80% of its initial PCE value after 1100 h aging, indicating a remarkable improvement in operational stability by SAL:P strategy. Furthermore, the photostability of the encapsulated devices has been also tested under the continuous illumination (AM 1.5 G) condition for continuous maximumpower-point tracking. As shown in Fig. 2-9(b), the SAL:P device shows better photostability and sustained over 80% of its initial PCE after 750 h, whereas the DE and SAL device underwent a severe PCE drop. Overall, SAL-based PSCs have better stability than DE-based PSCs and passivated PSCs show an elongated device lifetime which does not exactly follow the photovoltaic performance of PSCs. This result plausibly indicates that the larger crystal sizes and fewer grain boundaries are the key factors in PSCs' long-term device stability, and the passivation layer effectively improves the perovskite/HTL interface and thus elongates the device lifetime [14,31,32]. Further studies are to be performed on the stability and photovoltaic performance of PSCs results, including the roles of solvent's functional groups in the device performance and the long-term degradation mechanisms.



Fig. 2-9. Long-term stability of the perovskite solar cells. (a) Thermal stability of encapsulated DE, SAL and SAL:P devices under the 60 °C, ambient air condition. (b) Photostability of the encapsulated DE, SAL and SAL:P devices under the continuous illumination (AM 1.5 G) condition for the continuous maximum-power-point tracking.

2.4. Conclusions

Although PSCs have gathered large attention due to their outstanding performance and cost benefits, only a few studies exist on safety management in the fabrication process. In most cases, hazardous solvents, based on health, flammability and reactivity cause a risk to the user and manufacturing process safety. This work successfully utilized the multi-functioning green solvent SAL in PSCs and achieved PCE up to 20.23% with largely improved stability under extreme conditions. XRD, PL and impedance analysis indicate that green solvent method enhanced charge transporting characteristics at the perovskite/HTL interface. This semipolar solvent could be utilized as both antisolvent and functional solvent to dissolve passivation agents, suggesting that SAL can be a safer alternative solvent for environmentally friendly fabrication in the PSCs process. The multi-functional SAL method can significantly reduce systematic health risk, providing wider applications in user safety and the commercialization of PSCs.

2.5. References

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Abstract in Korean

페로브스카이트는 최근 고효율 페로브스카이트 태양 전지를 달성하기 위한 주요 후보 중 하나로 간주되었습니다. 그러나 현재의 PSC 절차는 일반적으로 PSC 의 대규모 상업화에 바람직하지 않은 다량의 독성이 강한 할로겐화 용매 또는 고인화성 용매에 의존합니다.

따라서 페로브스카이트 태양 전지 제조를 위한 보다 친환경적인 용매를 찾는 것이 지속 가능성을 개선하고 건강 위험을 줄이는 데 중요합니다. 본 연구는 안티솔벤트 및 후처리 용매로서 무독성 및 비할로겐화 살리실알데히드를 사용합니다. 살리실알데히드는 메밀에서 추출할 수 있는 비반응성, 내염성 및 건강 위험이 없는 반용매로 활용되어 제조 공정에서 안전성을 보장합니다. 또한 이 용매는 벤젠 고리에 부착된 수산기(-OH)로 인해 극성 특성을 가지므로 다양한 용매를 용해시킬 수 있습니다.

그 결과, 그린 솔벤트를 이용한 페로브스카이트 태양전지는 기존 유해 솔벤트와 비슷한 효율을 달성했습다. 본연구는 살리실알데히드가 페로브스카이트 태양 전지 공정에서 환경 친화적인 제조를 위한 더 안전한 대체 용매가 될 수 있음을 보여줍니다.

주요어 : 페로브스카이트 태양전지, 살리실알데히드, 친환경 용매, 소자 안정성

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