ALD Applications
Room 107-109 - Session AA2-TuM

Photo-Chemical Energy

Moderators: Jae Young Hur, Cheonnam National University, Xueliang (Andy) Sun, University of Western Ontario

10:45am **AA2-TuM-12 Efficient Photoelectrochemical H_2 Generation using Molybdenum Disulfide Film on Black Si Photocathode *via* Wafer-scale Atomic Layer Deposition***, ***Dae Woong Kim***, *D Kim, T Park,* Hanyang University, Republic of Korea

The hydrogen is an energy source spotlighted as an eco-friendly environmental fuel to replace fossil fuels. Photoelectrochemical (PEC) water splitting is one of the most promising methods for producing such hydrogen. However, high cost of noble metal catalysts such as Pt and low stability of Si photocathode need to be overcome. MoS_2 is an earth-abundant and low-cost electrocatalyst material for hydrogen evolution enabling to substitute for noble metal catalysts. [1] Atomic layer deposition (ALD) is proposed as a reliable and atomic scale-adjustable process for growing MoS_2 directly on Si photocathode with an exact thickness and composition. Furthermore, wafer-scale uniformity of the film even on a complicated nanostructure facilitates a mass production.

In this work, ALD amorphous MoS_2 film was grown on Si photocathode forming a Schottky junction at the interface of MoS_2/Si photocathode, which reduced the overpotential and improved stability of Si photocathode resulting in improved photovoltaic characteristics. Figure 1 shows typical photoelectrochemical current density curves of the PEC cells with MoS_2 layers with various thicknesses. Detailed experimental results will be presented.

References

[1] K. C. Kwon, S. Choi, K. Hong, C. W. Moon, Y-S Shim, D. H. Kim, T. Kim, W. Sohn, J-M Jeon, C-H Lee, K. T. Nam, S. Han, S. Y. Kim and H. W. Jang, Energy Environ. Sci. 9 (2016), 2240.

11:00am **AA2-TuM-13 Junction Interface Passivation by ALD in CIGS Solar Cells***, **Wei-Lun Xu***, National Tsing Hua University, Republic of China*; N Koothan,* Instrument Technology Research Center, Republic of China*; J Huang,* Institute of NanoEngineering and MicroSystems*; Y Yu,* Instrument Technology Research Center, Republic of China*; C Ke,* Instrument Technology Research Center*; C Lai,* National Tsing Hua University, Republic of China

Increasing the efficiency of CIGS solar cells is of a crucial topic. One way of increasing the performance of CIGS solar cells is to grow a passivation layer between the CIGS and the buffer layer. The chemical and charge property of passivation layer is used to reduce the recombination between p-type and n-type and helps to increase the efficiency but the layer has to be grown in a certain way that it does not affect the current flow between the absorber layer and buffer layer. Also, the texture of the junction passivation layer has to be maintained to have a better interface. The ALD technique is known for its uniformity and conformal coverage, therefore the junction layer was deposited by ALD without needing any additional patterns. For the first time, we explore the effect of junction interface passivation with different materials including HfO_2 and AlO_x. The mechanism of the passivation effect is discussed in detail. Based on the results, suggestion for the best practice for the passivation is also discussed.

11:15am **AA2-TuM-14 Spatial Atomic Layer Deposition: Up-scalable Route of Metal Oxide Functional Layers for High Efficient and Stable Perovskite Solar Cells and Modules***, **Valerio Zardetto***, TNO/Holst Center, Netherlands*; M Najafi, D Zhang,* ECN, Netherlands*; F Di Giacomo,* TNO/Holst Center*; I Dogan,* TNO/Holst Center, Netherlands*; W Verhees,* ECN, Netherlands*; A Senes, H Lifka, H Fledderus, F van de Bruele,* TNO/Holst Center, Netherlands*; S Veenstra,* ECN, Netherlands*; R Andriessen,* TNO/Holst Center, Netherlands*; P Poodt,* Holst Centre - TNO, Netherlands

Atomic layer deposition (ALD) technique is well acknowledged to fabricate dense, conformal, uniform films over large area with an accurate control of the deposited thickness. ALD has been widely explored in several applications including photovoltaics (PV). In the last 5 years, organometallic halide perovskite solar cells (PSCs) attracts the interest in the PV community, due to the rapid increase in power conversion efficiency (PCE). However, the high performance has been achieved adopting lab scale techniques such as spin coating on small area (< 0.2cm^2).[1] In order to move PSC towards commercialization, large area sheet-to-sheet (S2S) and/or roll-to-roll (R2R) deposition methods are required. Whilst ALD technique has been adopted to deposit several functional metal oxides layers,[2] low deposition rates and the presence of expensive vacuum systems are not desired in the case of a low cost photovoltaic technology based on in-line large area manufacturing processes. Atmospheric pressure spatial atomic layer deposition (s-ALD) can couple the benefits of conventional ALD technique with high deposition rates and the absence of vacuum systems.[3]

In this contribution, we demonstrate the beneficial effect of the introduction of n-type s-ALD layers such as ZnO, TiO_2 and SnO_2 in the perovskite "p-i-n" planar perovskite solar cell. The presence of the s-ALD layer is found crucial to replace the conventional metal top electrode with a semitransparent sputtered ITO, which is required for hybrid tandem PV architectures (i.e., in combination with silicon solar cells). The s-ALD layer prevents sputtering damages during ITO deposition, enabling devices with efficiency up to 17% on small area (0.04 cm^2) and up to 13.5% on an integrated series connected mini-module (4 cm^2). The presence of the s-ALD layer increases the device stability during thermal aging tests. Our standard PSC degrades extremely fast when stressed at 85^{o}C in N_2 environment, losing 90% of the initial performance (PCE_0) after 500hrs. The introduction of s-ALD ZnO enables the device to retain more than the 80% of the PCE_0 after 900hrs. Furthermore, we explored the deposition of s-ALD layers n-type layers in "p-i-n" PSC where the p-type contact and the intrinsic perovskite films have been deposited via S2S slot-die technique. We observe that s-ALD SnO_2 process delivers higher performance (16% with Al electrode, and 14% with sputtered ITO) with respect to the s-ALD-free PSC (15% with Al contact).

Yang, W. S. *et al.Science* **356,** 1376–1379 (2017).

Zardetto, V. *et al.Sustain. Energy Fuels* **1,** 30–55 (2017).

Poodt, P. *et al.J. Vac. Sci. Technol. A Vacuum, Surfaces, Film* **30,** 10802 (2012)

11:30am **AA2-TuM-15 Applications of Atomic Layer Deposition in Solar Energy Conversion***, **Xianglin Li***, Z Wang, H Fan, A Tok,* Nanyang Technological University, Singapore

Atomic layer deposition (ALD) provides a unique tool for the growth of thin films with excellent conformity and thickness control down to atomic levels. The application of ALD in solar energy research has received increasing attention in recent years. The research focus of our work is focused on the fabrication, surface passivation of nanostructured photoelectrodes based on ALD technique. Various of "host & guest" type composite photoanodes have been designed and fabricated for efficient photoelectrochemical (PEC) water splitting based on ALD. In such a design, a highly porous and conductive nanostructures act as the "host" skeleton it provides direct pathways for faster electron transport, while the conformally coated semiconductor layers act as the "guest" absorber layer. For example, 3D FTO/FTO-NR/TiO_2 composite invers opal structure, Nb--SnO_2 nanosheet/TiO_2 and Nb--SnO_2 nanosheet/Fe_2O_3 heterostructures were designed for PEC water splitting application. Also the ALD thin layer surface passivation and ALD ZnSnO, Zn(O, S) Cd-free buffer layers for CIGS solar cells were studied. Challenges and future directions of ALD in the applications of solar conversion will be discussed.

11:45am **AA2-TuM-16 Inorganic Charge Transport Layers Grown via Atomic Layer Deposition for Highly Stable and Efficient Perovskite Solar Cell***, **Seongrok Seo***, S Jeong, C Bae, N Park, H Shin,* Sungkyunkwan University, Republic of Korea

Despite the high power conversion efficiency (PCE) of perovskite solar cells (PSCs), poor long-term stability is one of the main obstacles preventing their commercialisation. Several approaches to enhance the stability of PSCs have been proposed. However the accelerating stability test of PSCs at high temperature under the operating conditions in ambient air remains still to be demonstrated. Herein, we show interface engineered stable PSCs with inorganic charge transport layers (*p*-NiO and *n*-Al:ZnO grown *via* atomic layer deposition (ALD)). First of all, NiO has been chosen as hole transporting layers due to its a wide band gap (~3.6 eV) and *p*-type semiconducting porperties. It also has good optical transparency and high chemical stability, and thus has the capability aligning the band edges to the perovskite ($CH_3NH_3PbI_3$) layers with efficient energy transfer. Ultra-thin and un-doped NiO films with much less absorption loss were prepared by ALD with highly precise control over thickness without any pinholes. Thin enough (5–7.5 nm in thickness) NiO films with the thickness of few time the Debye length (L_D = 1–2 nm for NiO) show enough conductivities achieved by overlapping space charge regions. Second, t he highly conductive Al doped ZnO films have been chosen as an efficient electron transporting

layers while acting as dense passivation layers. This layer prevents underneath perovskite from moisture contact, evaporation of component, and reaction with a metal electrode. Finally the inverted-type PSCs with inorganic charge transport layers exhibited a PCE of 18.45 % and retained 86.7 % of the initial efficiency for 500 hours under continuous 1-sun illumination at 85 °C in ambient air with electrical biases (at maximum power point tracking).

References

[1] S. Seo, I. J. Park, M. Kim, S. Lee, C. Bae, H. S. Jung, N. G. Park, J. Y. Kim, H. Shin, *Nanoscale* **2016**, *8*, 11403

[2] S. Seo, S. Jeong, C. Bae, N.G. Park, H. Shin, *Adv. Mater.* **2018** (in press)

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