**TECHNICAL ASSISTANCE REQUEST**

In our work we demonstrated a rear illuminated solar cell with intrinsically integrated $Li_4Ti_5O_{12}$-$LiCoO_2$ lithium ion battery (LIB) having overall efficiency of 7.3%[1] which is lower than the stand alone front illuminated perovskite solar cell with efficiency 18.74% [1] . This is due to the opaque nature of top electrode with overall transmittance of only 55% and the usage of external power electronics devices such as maximum power point tracking (MPPT) decreases the overall efficiency.

We are looking for technical assistance to overcome the above descried problems. In the following section we will discuss potential solutions and technical assistance expected for higher efficiency of the final integrated device.

**Transparent electrode:** We are planning to use transparent conductive oxides (TCO) such as Indium doped tin oxide (ITO), or ultrathin layer of carbon and silver nanowires[2] in composition with MoOx (Molybdenum Oxide) as top electrode in dielectric-metal-dielectric (DMD) structure [3, 4] with optimized thickness. The highly transparent top electrode for rear-illuminated solar cells can improve energy harvesting from solar cell that will eventually increase device efficiency.

We need to deposit Indium doped tin oxide (ITO) and silver nano wires that are highly transparent and conductive. We can achieve it by using radio-frequency (RF)-sputtering at lower temperatures to avoid perovskite deterioration. Since we do not have these facilities in our university, we request to use NREL's state of the art RF sputtering for depositing ITO and inkjet printing or ultrasonic spray deposition[5] for Transparent silver nano wires deposition in the DMD structure. These facilities are readily available on Process development and integration laboratory (PDIL) collaborative facility, NREL.

**Large Area Perovskite solar cell:** We used small cell area of 0.13 $cm^2$, but large cell area is preferred for commercialization. For developing large area solar cell, the major obstacle is lack of scalable approach. Recently Gu, Wang et al.[6] developed scalable perovskite using confined space sublimation to develop large area of 6.75 $cm^2$ solar cells with comparable efficiency at 18.41%.

In lab scale, using solution processable method, we were able to achieve an efficiency of 20% with grain boundary defect passivation in mixed cation n-i-p structure.[7] Since NREL regularly attains highly reproducible perovskite solar cells with >20% efficiencies for $1cm^2$ square area with Atmospheric processing platform. We are requesting to use processes such as large-area ultrasonic spray deposition and large-area rapid thermal processing available at NREL's atmospheric processing platform for fabricating perovskite solar cells by using our perovskite materials through the voucher coupons provided for the solar prize winners.

**Perovskite Module:** The next step is to develop a perovskite module consisting perovskite solar cells in series or perovskite tandem structures and interconnect these modules for large cell area. Since most of the LIBs used in low power applications needs around 3V for charging, the output voltage at MPPT should match or exceed battery voltage. In order to fully charge the batteries, solar modules with coupling factor ~ 1.0.[8] are needed. Our lab capability of developing solar modules in series with large area is limited. However, using NREL's Atmospheric processing platform which has facilities such as sample handling, material deposition, processing, measurements and characterization, we will be able to efficiently fabricate perovskite solar cell module in series with high output voltage for small scale applications.

**Solid state Battery:** Our proposed final prototype would incorporate perovskite solar cells in series integrated with solid-state batteries. When using solid state batteries, the roll-to-roll processing is viable, so it is favorable for commercialization.

Our team has already started preliminary research on assembling all-solid-state batteries. Major hurdles we are facing are the interfacial mismatch between anode and electrolyte or cathode and electrolyte layers. Thus, we would like to get the assistance on advanced thin film deposition of anode and cathode layers on solid electrolyte. For deposition of such interfacial layer on solid-electrolytes, thin film deposition systems such as Plasma-enhanced chemical vapor deposition (PECVD), Physical vapor deposition (PVD), Atomic layer deposition (ALD), RF sputtering etc. will be used from NREL's PDIL facility. Along with it, characterization technique such as X-ray photoelectron spectroscopy (XPS), at PDIL can help us to know effects of these interfacial layer on battery chemistries.

NREL can also assist us for the commercialization push of our integrated designs. As "jelly-roll" architecture of solid-state batteries is very much feasible, and perovskite solar cells are already proven to be flexible. By monolithically stacking them one on the top of another we can definitely set our goal to achieve roll-to roll processing of such perovskite solar cell and solid-state battery integrated designs. NREL with lab facilities such as energy systems fabrication laboratory, energy systems integration facility and manufacturing laboratory with infrastructures for continuous roll-to-roll processing, benchtop roller prototypes, dual laser thickness instrumentation can assist us in product manufacture for prompt commercialization of these integrated devices.

## References:


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