Student Checklist (1A)

This form is required for ALL projects.

1. a. Student/Team Leader: Ethan Eisenberg Grade: 11th grade

   Email: etheisenberg@gmail.com Phone: 516-602-8059

   b. Team Member: Jack Cox c. Team Member: ____________

2. Title of Project:

   Stability Enhancement of Perovskite Solar Cells Using Mixed Cation/Halide Perovskite

3. School: Hewlett High School School Phone: 516-792-4001

   School Address: 60 Everit Avenue, Hewlett, NY, 11557

4. Adult Sponsor: Dr. Terrence Bissoondial Phone/Email: tbissoondial@hewlett-woodmere.net

5. Does this project need SRC/IRB/IACUC or other pre-approval? ☐ Yes ☒ No Tentative start date: 07/05/2019

6. Is this a continuation/progression from a previous year? ☐ Yes ☒ No

   If Yes:

   a. Attach the previous year's ☐ Abstract **and** ☐ Research Plan/Project Summary

   b. Explain how this project is new and different from previous years on

   ☐ Continuation/Research Progression Form (7)

7. This year's laboratory experiment/data collection:

   07/05/2019 — Actual Start Date: (mm/dd/yy)

   08/15/2019 — End Date: (mm/dd/yy)

8. Where will you conduct your experimentation? (check all that apply)

   ☒ Research Institution ☐ School ☐ Field ☐ Home ☐ Other: ____________

9. List name and address of all non-home and non-school work site(s):

   Name: Stony Brook University

   Address: 100 Engineering Dr, Stony Brook, NY 11794

   Phone/email: Dr. Miriam Rafailovich: 516-458-9011

10. **Complete a Research Plan/Project Summary following the Research Plan/Project Summary instructions and attach to this form.**

11. **An abstract is required for all projects after experimentation.**

Research Plan/Project Summary Instructions

A complete Research Plan/Project Summary is required for ALL projects and must accompany Student Checklist (1A).

1. All projects must have a Research Plan/Project Summary
   a. Written prior to experimentation following the instructions below to detail the rationale, research question(s), methodology, and risk assessment of the proposed research.
   b. If changes are made during the research, such changes can be added to the original research plan as an addendum, recognizing that some changes may require returning to the IRB or SRC for appropriate review and approvals. If no additional approvals are required, this addendum serves as a project summary to explain research that was conducted.
   c. If no changes are made from the original research plan, no project summary is required.

2. Some studies, such as an engineering design or mathematics projects, will be less detailed in the initial project plan and will change through the course of research. If such changes occur, a project summary that explains what was done is required and can be appended to the original research plan.

3. The Research Plan/Project Summary should include the following:
   a. **RATIONALE:** Include a brief synopsis of the background that supports your research problem and explain why this research is important and if applicable, explain any societal impact of your research.
   b. **RESEARCH QUESTION(S), HYPOTHESIS(ES), ENGINEERING GOAL(S), EXPECTED OUTCOMES:** How is this based on the rationale described above?
   c. Describe the following in detail:
      - **Procedures:** Detail all procedures and experimental design including methods for data collection. Describe only your project. Do not include work done by mentor or others.
      - **Risk and Safety:** Identify any potential risks and safety precautions needed.
      - **Data Analysis:** Describe the procedures you will use to analyze the data/results.
   d. **BIBLIOGRAPHY:** List major references (e.g. science journal articles, books, internet sites) from your literature review. If you plan to use vertebrate animals, one of these references must be an animal care reference.

Items 1–4 below are subject-specific guidelines for additional items to be included in your research plan/project summary as applicable.

1. **Human participants research:**
   a. **Participants:** Describe age range, gender, racial/ethnic composition of participants. Identify vulnerable populations (minors, pregnant women, prisoners, mentally disabled or economically disadvantaged).
   b. **Recruitment:** Where will you find your participants? How will they be invited to participate?
   c. **Methods:** What will participants be asked to do? Will you use any surveys, questionnaires or tests? If yes and not your own, how did you obtain? Did it require permissions? If so, explain. What is the frequency and length of time involved for each subject?
   d. **Risk Assessment:** What are the risks or potential discomforts (physical, psychological, time involved, social, legal, etc.) to participants? How will you minimize risks? List any benefits to society or participants.
   e. **Protection of Privacy:** Will identifiable information (e.g., names, telephone numbers, birth dates, email addresses) be collected? Will data be confidential/anonymous? If anonymous, describe how the data will be collected. If not anonymous, what procedures are in place for safeguarding confidentiality? Where will data be stored? Who will have access to the data? What will you do with the data after the study?
   f. **Informed Consent Process:** Describe how you will inform participants about the purpose of the study, what they will be asked to do, that their participation is voluntary and they have the right to stop at any time.

2. **Vertebrate animal research:**
   a. Discuss potential ALTERNATIVES to vertebrate animal use and present justification for use of vertebrates.
   b. Explain potential impact or contribution of this research.
   c. Detail all procedures to be used, including methods used to minimize potential discomfort, distress, pain and injury to the animals and detailed chemical concentrations and drug dosages.
   d. Detail animal numbers, species, strain, sex, age, source, etc., include justification of the numbers planned.
   e. Describe housing and oversight of daily care
   f. Discuss disposition of the animals at the termination of the study.

3. **Potentially hazardous biological agents research:**
   a. Give source of the organism and describe BSL assessment process and BSL determination.
   b. Detail safety precautions and discuss methods of disposal.

4. **Hazardous chemicals, activities & devices:**
   - Describe Risk Assessment process, supervision, safety precautions and methods of disposal.
   - Material Safety Data Sheets are not necessary to submit with paperwork.

Stability Enhancement of Perovskite Solar Cells Using a Mixed Cation/Halide Perovskite
Student Names: Ethan Eisenberg and Jack Cox

Project Category: Energy and Materials Science

A. Rationale:

A lack of renewable resources requires exploring and utilizing alternative forms of energy e.g solar energy (Fan, *et al.,* 2014). In recent years, organic-inorganic hybrid perovskite solar cells (PSCs) have emerged as a potential asset for thin film, low cost photovoltaics (H.J. Snaith, 2013). Perovskites have the common structure ABX_3 that is comprised of a monovalent cation, A=cesium ($Cs+$), methylammonium (MA), formamidinium (FA); (Saliba *et al.*, 2016), a divalent metal; B=(Pb^{2+}; Sn^{2+}) (Kim *et al.,* 2012; Stoumpos *et al*, 2014); and a halide anion X=(Cl^-, Br^-; I^-) (Noh *et al*, 2013). These materials have been shown to be beneficial in their optoelectronic capabilities. Perovskites exhibit high optical absorption coefficients (De Wolf *et al.* 2012) and long charge carrier diffusion lengths in the micrometer range (Xing *et al.,* 2013). Perovskite solar cells include characteristics such as tunable bandgaps, ambipolar carrier transport, and a high resistance to impurities (Xiao, *et al.*, 2017). Despite its advantages, perovskites are limited by their instability. Single organic cation perovskite cells such as $FAPbI_3$ or the $MAPbI_3$ classic structure degrade when left in ambience. Moreover, perovskites are also limited in their overall efficiency by their open-circuit voltage (Voc), which can be improved upon by filtering charge carriers through a photoactive layer (Seo *et al.,* 2016; Albrecht *et al*., 2016; Hadadian *et al.,* 2016). The overall efficiency of perovskite cells are also limited by the crystal quality, in which impurities are found in FA-based perovskites, such as $FAPbI_3$ (Saliba *et al.,* 2016). In these PSCs, a yellow, photo-inactive polymorph phase exists, which includes a wider bandgap. This is referred to as the delta phase, and restricts electron movement. However, through the implementation of the CsFAMAPbIxBr1-x mixed cation/halide perovskite structure, it is possible to reduce the delta phase within the $FAPbI_3$ perovskite as well as attain a higher efficiency.

B.

Question of Problem being addressed:

How does a mixed cation/halide perovskite structure influence its stability and efficiency?

Hypothesis/Engineering goals:

The mixed cation/halide structure will enhance both the stability and efficiency of the cell. The FA cation is believed to optimize the bandgap, as seen when it is placed in the $FAPbI_3$ structure. In this case, the bandgap is 1.48 eV. This bandgap is preferable in that there is a lower distance required for the electrons to travel from the valence band to the conduction band, allowing for electrons to be more easily excited. In addition, the Cs cation and Br halide are believed to enhance the stability of the perovskite cell by reducing degradation into its yellow photo inactive phase. By reducing phase transformation and optimizing the bandgap, the perovskite solar cell is believed to have enhanced absorption, efficiency, and stability.

C. Procedure:

Cleaning of the Fluorine-Doped Tin Oxide (FTO) Layer:

1. First, FTO glass pieces will be cut into 1.4cm x 1.4cm wafers and placed in an acetone solvent. This will be completed under the fume hood. The wafers will then be sonicated for 10 minutes to vibrate the material and remove the possible contaminants. This will be done using a sonicator, with distilled water serving as the medium.
2. The FTO slides will then be bathed in isopropyl alcohol while sonicated for 10 minutes using a sonicator as well.
3. The FTO slides will then be bathed in ethyl alcohol and sonicated for 10 minutes using an identical sonicator.
4. A UV-Ozone facility will emit ionized oxide(O_3) in combination with UV-light to allow for a more cleaned surface
5. FTO wafers will be tested for their ohmic value using a multimeter to determine electric resistance, and determine which side of the FTO glass is conductive. If the multimeter reveals values of 1 or infinity, then that given side is not conductive.

Preparation of the TiO_2 Electron Transport Layer

TiO_2 precursor will be prepared through the following process:

1. 1 milliliter of Titanium (IV) butoxide will be dissolved in 10 milliliters of ethanol for 30 minutes.
2. 1 milliliter of ethanoic acid will be added and stirred for 30 minutes using a magnetic stirrer (stir bar).
3. 1 milliliter of acetylacetone will be added and stirred for 30 minutes.
4. 1 milliliter of de-ionized water will be added and stirred for 30 minutes.
5. FTO pieces will be spin-coated with TiO_2 solution at 2,000 rpm for 30 seconds to produce thin films, which will be done under the fume hood.
6. Once spin casted, the washed FTO glasses will be undergo pyrolysis on a hotplate at 465 Celsius for two hours. This will induce the formation of an electron transport layer (ETL) through a sol-gel (chemical solution deposition) reaction. This will be completed under the fume hood.
7. To observe morphological data (AFM and SEM), glass pieces will be cut using diamond cutters into 1.3cm by 1.3 cm wafers. The washing and spin casting process will be identical to the FTO glass.

Addition of the Perovskite Precursor, Spiro-OMeTAD, and Gold Electrodes

The one-step spin-coating method will be used to prepare the mixed cation/halide perovskite film:

1. PbI_2, MAI, CsI, FAI, and $PbBr_2$at a molar ratio of 1:.7:0.15:0.15 will be placed in a mixed solvent of Dimethyl Formamide (DMF) and Dimethyl Sulfoxide(DMSO) and left overnight in a magnetic stirrer. The perovskite will be uniformly mixed.
2. The perovskite precursor will be deposited onto the TiO_2 glass via spin coating at 4,000 rpm for 30 seconds.
3. Chlorobenzene will act as the antisolvent, and will be dipped onto the surface to induce crystal generation.
4. The as casted film will then be annealed at 100 C for 10 minutes.
5. The Spiro-OMeTAD layer will be coated at 4,000 rpm for 30 seconds as a hole transport layer (HTL)
6. Physical vapor deposition (PVD) will be used to add the gold electrodes.

The Perovskite (photoactive layer) and Spiro-OMeTAD((HTL) will be added in a glove box: Temperature and humidity are going to be regulated to prevent facile degradation

Data Analysis-Imaging

1. A nanoscale imaging tool will be used to measure grain sizes of the mixed cation/halide and control perovskites.
2. Image J will be used to set the scale for scanning electron microscopy

Risk and Safety:

Safety Data Sheets from ThermoFisher Scientific, Sigma Aldrich, Ozone Solutions, and Ecletic, were used for all the chemicals

Acetone- Highly flammable liquid and vapor, causes serious eye irritation, may cause drowsiness or dizziness, and may cause damage to organs through prolonged or repeated exposure. Gloves, goggles and lab coats will be worn when handling. The acetone will be stored in the flammables area in a tightly closed container, and stored in a well-ventilated place away from heat and sources of ignition. The acetone will be disposed according to official regulations by the chemical safety officer of Stony Brook University.

https://www.fishersci.com/shop/msdsproxy?productName=AC177170010&productDescription=ACETONE

Isopropyl Alcohol- Highly flammable liquid and vapor. May cause serious eye irritation, drowsiness, or dizziness. Gloves, goggles and lab coats will be worn when handling. When storing, the isopropyl alcohol will be kept away from sources of ignition, and there will be no smoking. Measures will be taken to prevent the build up of electrostatic charge. The container will be tightly closed in a dry and well-ventilated place, and containers that are opened must be carefully resealed and kept upright to prevent leakage. The isopropyl alcohol will be disposed according to the official regulations by the chemical safety officer of Stony Brook University.

https://www.sigmaaldrich.com/MSDS/MSDS/DisplayMSDSPage.do?country=US&language=en&productNumber=W292907&brand=ALDRICH&PageToGoToURL=https%3A%2F%2Fwww.sigmaaldrich.com%2Fcatalog%2Fproduct%2Faldrich%2Fw292907%3Flang%3Den

Ethyl Alcohol- Highly flammable liquid and vapor. Causes serious eye irritation, damage to organs, and damage to organs through prolonged or repeated exposure. Personal protective equipment such as gloves, goggles, and lab coats will be worn in the lab. Adequate ventilation will be ensured. The ethyl alcohol will not get in eyes, skin, or clothing, and will be avoided from ingesting and inhaling. For storage, containers will be kept in a tightly closed in a dry, cool and well-ventilated place. Containers will also be kept away from heat and sources of ignition. The ethyl alcohol will be disposed according to the official regulations by the chemical safety officer of Stony Brook University.

https://www.fishersci.com/msdsproxy%3FproductName%3DA405P4%26productDescription%3DETHANOL%2BAHYD%2BHISTO%2B4L%26catNo%3DA405P-4%2B%26vendorId%3DVN00033897%26storeId%3D10652

Titanium (IV) butoxide- Flammable liquid and vapor. Causes skin irritation and serious eye damage. May also cause respiratory irritation, drowsiness, or dizziness. . Avoid contact with skin and eyes. Avoid inhalation of vapor or mist. Keep away from sources of ignition - No smoking. Measures will be taken to prevent the buildup of electrostatic charge. For safe storage, the container will be tightly closed in a dry and well-ventilated place. Proper equipment will be worn such as gloves, goggles, and lab coats. Containers which are opened must be carefully resealed and kept upright to prevent leakage. The Titanium (IV) butoxide will be disposed according to the official regulations by the chemical safety officer of Stony Brook University.

https://www.sigmaaldrich.com/MSDS/MSDS/DisplayMSDSPage.do?country=US&language=en&productNumber=244112&brand=ALDRICH&PageToGoToURL=https%3A%2F%2Fwww.sigmaaldrich.com%2Fcatalog%2Fproduct%2Faldrich%2F244112%3Flang%3Den

Ethanoic Acid- Flammable liquid and vapor. Causes severe skin burns and eye damage. May be harmful if swallowed. Toxic if inhaled. Harmful if in contact with skin. The ethanoic acid will be stored in a cool location where ventilation will be provided for containers. Proper protection equipment will be worn such as gloves, goggles, and lab coats. Storage near extreme heat, ignition sources, or an open flame will be avoided. The container will be tightly sealed and if opened, resealed and kept upright to prevent leakage. The ethanoic acid will be disposed according to the official regulations by the chemical safety officer of Stony Brook University.

https://betastatic.fishersci.com/content/dam/fishersci/en_US/documents/programs/education/regulatory-documents/sds/chemicals/chemicals-a/S25118.pdf

Acetylacetone- Flammable liquid and vapor. Harmful if swallowed. Toxic if in contact with skin or inhaled. Container will be tightly closed in a dry and well-ventilated place. Containers which are opened must be carefully resealed and kept upright to prevent leakage. Proper laboratory equipment such as gloves and goggles will be worn. Acetylacetone will be disposed according to the official regulations by the chemical safety officer of Stony Brook University

https://www.sigmaaldrich.com/MSDS/MSDS/DisplayMSDSPage.do?country=US&language=en&productNumber=A3511&brand=SIGMA&PageToGoToURL=https%3A%2F%2Fwww.sigmaaldrich.com%2Fcatalog%2Fproduct%2Fsigma%2Fa3511%3Flang%3Den

PbI_2- Harmful if swallowed or if inhaled. May cause cancer. May cause damage to organs through prolonged or repeated exposure. Gloves, goggles, and lab coats will be worn. Container will be kept tightly closed in a dry and well-ventilated place. PbI_2 will be disposed according to the official regulations by the chemical safety officer of Stony Brook University.

https://www.sigmaaldrich.com/MSDS/MSDS/DisplayMSDSPage.do?country=US&language=en&productNumber=203602&brand=ALDRICH&PageToGoToURL=https%3A%2F%2Fwww.sigmaaldrich.com%2Fcatalog%2Fsearch%3Fterm%3DPbI2%26interface%3DAll%26N%3D0%26mode%3Dpartialmax%26lang%3Den%26region%3DUS%26focus%3Dproduct

MAI- Harmful if swallowed. Causes skin irritation. Causes serious eye irritation. May cause respiratory irritation. Will be kept in a tightly closed container and in a dry and well-ventilated place. Gloves, goggles, and lab coats will be worn. MAI will be disposed according to the chemical safety officer of Stony Brook University.

https://www.sigmaaldrich.com/MSDS/MSDS/DisplayMSDSPage.do?country=US&language=en&productNumber=793493&brand=ALDRICH&PageToGoToURL=https%3A%2F%2Fwww.sigmaaldrich.com%2Fcatalog%2Fproduct%2Faldrich%2F793493%3Flang%3Den

CsI- Causes skin irritation. May cause an allergic skin reaction. Causes serious eye irritation. May cause respiratory irritation. Gloves, goggles, and lab coats will be worn. Will be kept in a tightly closed container and in a dry and well-ventilated place. Will be disposed according to the chemical safety officer of Stony Brook University

https://www.sigmaaldrich.com/MSDS/MSDS/DisplayMSDSPage.do?country=US&language=en&productNumber=203033&brand=ALDRICH&PageToGoToURL=https%3A%2F%2Fwww.sigmaaldrich.com%2Fcatalog%2Fproduct%2Faldrich%2F203033%3Flang%3Den

FAI- Harmful if swallowed. Causes skin irritation Causes serious eye irritation. May cause respiratory irritation Gloves, goggles, and lab coats will be worn. Will be kept in a tightly closed container in a dry, and well-ventilated place. Will be disposed according to the chemical safety officer of Stony Brook University.

https://www.sigmaaldrich.com/MSDS/MSDS/DisplayMSDSPage.do?country=US&language=en&productNumber=806048&brand=ALDRICH&PageToGoToURL=https%3A%2F%2Fwww.sigmaaldrich.com%2Fcatalog%2Fproduct%2Faldrich%2F806048%3Flang%3Den

$PbBr_2$- Harmful if swallowed or if inhaled. May cause cancer. May cause damage to organs through prolonged or repeated exposure. Gloves, goggles, and lab coats will be worn. Will be kept in a tightly closed container in a dry, and well-ventilated place. Will be disposed according to the chemical safety officer of Stony Brook University.

https://www.sigmaaldrich.com/MSDS/MSDS/DisplayMSDSPage.do?country=US&language=en&productNumber=398853&brand=ALDRICH&PageToGoToURL=https%3A%2F%2Fwww.sigmaaldrich.com%2Fcatalog%2Fproduct%2Faldrich%2F398853%3Flang%3Den

DMF- Flammable liquid and vapor. Harmful in contact with skin or if inhaled. Causes serious eye irritation. Gloves, goggles, and lab coats will be worn. Will be kept in a tightly closed container in a dry, and well-ventilated place. Containers which are opened will be carefully resealed and kept upright to prevent leakage. Will be disposed according to the chemical safety officer of Stony Brook University.

https://www.sigmaaldrich.com/MSDS/MSDS/DisplayMSDSPage.do?country=US&language=en&productNumber=D4551&brand=SIGMA&PageToGoToURL=https%3A%2F%2Fwww.sigmaaldrich.com%2Fcatalog%2Fproduct%2Fsigma%2Fd4551%3Flang%3Den

DMSO- Combustible liquid. Gloves, goggles, and lab coats will be worn. Will be kept in a tightly closed container in a dry, and well-ventilated place. Will be disposed according to the chemical safety officer of Stony Brook University.

https://www.sigmaaldrich.com/MSDS/MSDS/DisplayMSDSPage.do?country=US&language=en&productNumber=276855&brand=SIAL&PageToGoToURL=https%3A%2F%2Fwww.sigmaaldrich.com%2Fcatalog%2Fproduct%2Fsial%2F276855%3Flang%3Den

MABr- Harmful if swallowed. Causes skin irritation. Causes serious eye irritation. May cause respiratory irritation. Gloves, goggles, and lab coats will be worn. . Will be kept in a tightly closed container in a dry, and well-ventilated place. Will be disposed according to the chemical safety officer of Stony Brook University.

https://www.sigmaaldrich.com/MSDS/MSDS/DisplayMSDSPage.do?country=US&language=en&productNumber=806498&brand=ALDRICH&PageToGoToURL=https%3A%2F%2Fwww.sigmaaldrich.com%2Fcatalog%2Fproduct%2Faldrich%2F806498%3Flang%3Den

TiO_2- Not a hazardous substance or mixture. Nonetheless, gloves, goggles, and lab coats will be worn. Will be kept in a tightly closed container in a dry, and well-ventilated place. Will be disposed according to the chemical safety officer of Stony Brook University.

https://www.sigmaaldrich.com/MSDS/MSDS/DisplayMSDSPage.do?country=US&language=en&productNumber=791326&brand=ALDRICH&PageToGoToURL=https%3A%2F%2Fwww.sigmaaldrich.com%2Fcatalog%2Fsearch%3Fterm%3DTiO2%26interface%3DAll%26N%3D0%2B%26mode%3Dpartialmax%26lang%3Den%26region%3DUS%26focus%3Dproduct

Chlorobenzene - Flammable liquid and vapor. Causes skin irritation. Harmful if inhaled, Gloves, goggles, and lab coats will be worn. . Kept in a tightly closed container in a dry, and well-ventilated place. Will be kept away from heat and sources of ignition. Will be disposed according to the chemical safety officer of Stony Brook University.

https://www.fishersci.com/store/msds?partNumber=B2544&productDescription=CHLOROBENZENE+MONO+LAB+4L&vendorId=VN00033897&countryCode=US&language=en

Activities and Devices

For UV-Ozone Facility:

UV: Causes skin and eye irritation. May cause cancer. Personal protective equipment such as gloves, goggles, and lab coats will be worn. Will be stored in original container protected from direct sunlight in a dry, cool and well-ventilated area, away from incompatible materials and food and drink. Containers will be tightly closed and sealed until ready for use. Containers that have been opened must be carefully resealed and kept upright to prevent leakage.

https://www.tapplastics.com/uploads/pdf/E-6800UV_SDS.pdf

Ozone- Oxidizing gas. Causes skin irritation, eye irritation, and is toxic for respiratory systems. Proper safety equipment that include gloves, goggles, and lab coats will be worn in the lab. Ozone will be contained within ozone-resistant tubing and pipes from the generation point to the application point. Any leaks will be repaired before use.

http://www.ozoneapplications.com/info/Ozone%20Solutions%20MSDS%20Ozone.pdf

Hot Plate: More than minimal risk of skin irritation and slight burns.

Electrode: More than minimal risk of electric shock. Mentors will oversee use.

X-Ray Diffraction: X-rays may cause a slightly increased chance of cancer. Mentors will oversee use.

Data Analysis- Results:

Characterization of the Surface Morphology

1. Scanning Electron Microscopy (SEM) will be performed to investigate the grain size distribution of the mixed cation/halide perovskite in comparison to the $MAPbI_3$ control. Two different magnifications will be tested and a nanoscale imaging tool will be used to measure grain sizes. Mentors will oversee use.
2. Contact Atomic Force Microscopy (AFM) will be performed to investigate the roughness of the mixed cation/halide perovskite in comparison to the control. Root Mean Squared Values (RMS) will be calculated. Mentors will oversee use.

Characterization of UV-Visible Light Absorption

1. UV-Visible Spectroscopy will be performed to investigate the absorption capabilities of the mixed cation/halide perovskite. Mentors will oversee use.

Characterization of Crystal Phases

1. To observe the crystal phases within the mixed cation/halide perovskite in comparison to the control $MAPbI_3$, X-Ray diffraction(XRD) will be performed. Mentors will oversee use.

Characterization of Efficiency

1. To record the efficiency of the mixed cation/halide perovskite in comparison to the control, the photovoltaic will be connected to an electrode. Voltages and current densities will be used to produce a J-V curve and determine the Fill Factor. The Fill Factor will then be used in the equation Power Conversion Efficiency (PCE) =Jsc x Voc x Fill Factor(FF), with Jsc representing the current density when the voltage is 0 V, and Voc representing the voltage when the current density is 0 mA/cm^2. Mentors will oversee use.

Characterization of Stability

1. Perovskites will be tested for their stability when exposed to 76% humidity for a 24 hour period of time. Two perovskites will be tested, one with the addition of Cs. XRD will be performed to investigate the influence of Cs on the reduction of the delta phase. Mentors will oversee use.

D. Bibliography:

A. Kojima, K. Teshima, Y. Shirai, T. Miyasaka, Organometal halide perovskites as visible light sensitizers for photovoltaic cells. J Am Chem Soc 131, 6050-6051 (2009).

B. R. Li et al., Chlorobenzene vapor assistant annealing method for fabricating high quality perovskite films. Org Electron 34, 97-103 (2016).

C. Y. Yi et al., Entropic stabilization of mixed A-cation ABX(3) metal halide perovskites for high performance perovskite solar cells. Energ Environ Sci 9, 656-662 (2016).

Correa-Baena, Juan-Pablo, et al. "The Rapid Evolution of Highly Efficient Perovskite Solar Cells." Energy & Environmental Science, vol.10,no. 3, 2017,., doi:10.1039/c6ee03397k.

D. Bi et al., Using a Two-Step Deposition Technique To Prepare Perovskite($CH_3NH_3PbI_3$) for Thin Film Solar Cells Based on ZrO_2 and TiO_2 Mesostructures.

F. Hao, C. C. Stoumpos, D. H. Cao, R. P. H. Chang, M. G. Kanatzidis, Lead-free solid-state organic-inorganic halide perovskite solar cells. Nature Photonics 8, 489-494 (2014).

Fan, Jiandong, et al. "Perovskite-Based Low-Cost and High-Efficiency Hybrid Halide Solar Cells." *Photonics Research*, Optical Society of America, 11 Aug. 2014, www.osapublishing.org/prj/abstract.cfm?URI=prj-2-5-111.

Xiao, Jia-Wen, et al. "The Emergence of Mixed Perovskites and Their Applications as Solar Cells." Advanced Energy Materials, DOI:10.1002/aenm.201700491.3.

X. Li et al., A vacuum flash-assisted solution process for high-efficiency large-area perovskite solar cells. Science 353, 58-62 (2016).

Zhou, Yuanyuan, and Yixin Zhao. "Chemical Stability and Instability of Inorganic Halide Perovskites." Energy &1Environmental Science, vol. 12, no. 5, 2019,., doi:10.1039/c8ee03559h.

ADDENDUM

No changes were made to the research plan