Plan for experimental validation

The manufacture of materials, device fabrication, characterization, and performance analysis would be the usual steps involved in experimentally validating the performance of Al/FTO/SnS_2/PbS/SnS/Ni solar cell. The all-inclusive plan that follows is provided:

A. Materials Synthesis and Preparation

- **Substrate (FTO) Preparation:**
  - **Cleaning:** The initial steps are glass substrates of tin oxide (FTO) doped with fluorine. Before being dried with nitrogen, the substrates are cleaned using a series of sonication techniques in detergent, deionized water, acetone, and isopropanol.
  - **Etching:** If required, use a zinc powder and HCl solution to etch the FTO layer, defining the solar cell's active area.
- **SnS_2 Layer Deposition:**
  - **Chemical Bath Deposition (CBD):** Apply CBD to the FTO substrate to form a SnS_2 thin film. The bath typically contains a mixture of cadmium salt (such $Cd(NO_3)_2$), thiourea, ammonia, and deionized water.
  - **Annealing:** To increase adhesion and crystallinity, anneal the SnS_2 layer at about 300°C after deposition.
- **Absorber Layer (PbS) Deposition:**
  - **Synthesis of Absorber Materials:** Utilize solid-state or solution-based techniques to create **PbS** powder. X-ray diffraction (XRD) and scanning electron microscopy (SEM) are used to characterize the materials.
  - **Deposition:** To ensure regulated thickness and homogeneity, install the dual absorber layer using methods such as spin coating, heat evaporation, or sputtering. Depending on the planned device design, this layer may be a mixed deposition or a sequential deposition of PbS.

    - **Annealing:** Crystallinity can be enhanced by post-deposition annealing in an inert environment at the proper temperatures, which are typically between 100 and 300°C.

- **SnS Layer Deposition:**
    - **Thermal Evaporation/Sputtering:** As an HTL, cover the dual absorber with a thin coating of SnS. For efficient hole extraction, the thickness should be tuned, typically between 20 and 50 nm.
    - **Annealing:** To maximize the SnS characteristics, a mild annealing procedure may be required.

- **Ni Electrode Deposition:**
    - **Thermal Evaporation/Sputtering:** To create a top electrode, deposit the Ni contact layer using heat evaporation or sputtering. Gain a solid understanding of the underlying SnS layer.

- **Al Contact Deposition:**
    - **Thermal Evaporation/Sputtering:** Lastly, if required, affix an Al layer as a back contact to the FTO's rear side. Depending on the design, this stage may be completed after the front layers are deposited.

B. Device Fabrication

- **Layer Assembly:** The layers should be assembled as follows: Al/FTO/SnS_2/PbS/SnS/Ni. Ensure that each layer is deposited under closely watched conditions to prevent contamination and maintain interface quality.
- **Encapsulation:** Cover the thing to keep moisture and air from causing it to decay.

C. Characterization

- **Structural Characterization:**
    - **X-ray Diffraction (XRD):** To determine which crystallographic phases the materials in question are situated in.

- **Scanning Electron Microscopy (SEM) and Energy-Dispersive X-ray Spectroscopy (EDS):** To investigate the layer's thickness, chemistry, and surface shape.

- **Optical Characterization:**
  - **UV-Vis Spectroscopy:** To see the absorption spectra and figure out the absorber layers' bandgap.
  - **Photoluminescence (PL) Spectroscopy:** To evaluate the absorber layers' quality and locate any flaws or recombination sites.
- **Electrical Characterization:**
  - **Current-Voltage (J-V) Measurements:** To determine the PV parameters, including V_{OC}, J_{SC}, FF, and PCE.
  - **External Quantum Efficiency (EQE):** To quantify the photoreaction of the solar cell that is dependent on wavelength.
- **Impedance Spectroscopy:** To look into charge transport routes and recombination.

D. Performance Analysis

- **Stability Testing:** Analyze the stability of the solar cells in various lighting scenarios, temperature fluctuations, and meteorological factors (such as humidity).
- **Comparison with Theoretical Predictions:** Verify the device's behavior and effectiveness by comparing the experimental findings with theoretical models.

E. Optimization

- **Parameter Tuning:** Based on the first results, modify the annealing temperatures, deposition circumstances, and layer thicknesses to enhance the device's performance.
- **Repeat and Validate:** To guarantee uniformity and reproducibility of the results, create a large number of devices.

This method covers material production, device construction, characterization, and performance analysis, offering a thorough method for experimentally verifying the Al/FTO/SnS_2/PbS/SnS/Ni solar cell's performance.