Making nanoparticle ink for compound solar cells

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Hot-injection synthesis of copper indium sulfide produces suitable ink for printed photovoltaic devices.

Compound solar cells, such as those made from copper indium sulfide (CIS), copper indium gallium selenide (CIGS) and copper zinc tin sulfide/selenide (CZTS), are promising candidates for replacing silicon photovoltaic devices in the future. These types of cells have attractive properties including high efficiency (CIS: 12.5%, CIGS: 20.3%, CZTS: 10.1%) and stability. Further, there are many more fabrication methods for compound cells than for silicon devices. They can be prepared both at low pressure (vacuum methods) and at atmospheric pressure (non-vacuum methods) using various techniques. Two examples are vacuum co-evaporation, where the thin films used in the cell are fabricated by the evaporation of precursor materials, and non-vacuum printing, where the absorber layers are printed on a substrate using a paste or ink—a solution of nanoparticles of a specific substance dispersed in a solvent. However, to date, compound solar cells that achieved high efficiency were mostly fabricated using vacuum methods, which drives up the cost of these devices.

Non-vacuum fabrication methods are cheaper, with non-vacuum printing being a particularly promising technique since it is simple, fast, and can be used on a large scale. Our research focuses on fabricating printed CIS, CZTS and CIGS solar cells. The key aspect in producing these devices is synthesizing suitable ink. As the process for producing ink for all three types of devices is similar, here we describe only the synthesis of CIS ink. Our method to fabricate CIS nanoparticles is similar to that of Panthani and collaborators, but uses lower-cost materials.

To synthesize CIS nanoparticles, researchers typically use sulfur powder as a sulfur precursor, and metal-organic (high cost) or inorganic materials (low cost) to produce copper and indium. In our work, we employed inorganic materials including copper (II) chloride dihydrate (CuCl₂·2H₂O) and indium chloride (InCl₃), in addition to sulfur powder.

We synthesized CIS nanoparticles in a three-neck flask by an hot-injection method (see Figure 1). We started by mixing 1.125mmol CuCl₂·2H₂O (purity of 97.5%) and 1.25mmol InCl₃ (purity >98%) with 10ml of an oleylamine solvent. We inserted nitrogen gas into the flask and then removed it by rotary pump to purge oxygen, a process we repeated several times. After, we heated the mixture of copper and indium precursors and oleylamine solvent up to 130°C and kept it at this temperature for 30 minutes under low vacuum while stirring with a magnetic bar. We then increased the temperature to 200°C and injected 4mL of a solution of 1mol/L sulfur in oleylamine while keeping the temperature constant for 30 minutes. After the reaction was finished, the solution—a mixture of CIS nanoparticles and solvent at this stage—was cooled down to 60°C.

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To separate the nanoparticles, we combined the solution with a mixture of hexane and isopropanol, and centrifuged it at 3400 rotations per minute for 15 minutes. We repeated this washing process a few times until the solvent was completely removed. We then dried CIS nanoparticles under an inert gas, such as argon or nitrogen, and dispersed them in both toluene and hexanethiol solvents to make stable ink.

To analyze the phases existing in the powder after synthesis, we performed X-ray diffraction measurements of CIS nanoparticles coated on slide glass (see Figure 2). We observed diffraction peaks at 27.42, 46.14, and 54.88°, coinciding with the main peaks of CIS in the data reference of the Joint Committee for Powder Diffraction Standards, indexed as (112), (204)(220) and (312) orientations of CIS phase. This result indicates that only this phase exists in our nano powder. We also measured particle size using transmission electron microscopy, obtaining a diameter of around 10nm (see Figure 3).

In summary, we successfully synthesized desirable CIS nanoparticle ink to use in fabricating printed CIS solar cells. In the future, we will analyze how the composition of nanoparticles in the ink affects cell performance. We will also look into how performance depends on the annealing conditions (such as annealing time and temperature), buffer layers and window layers in the cell.

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Duy-Cuong Nguyen is a post-doctoral researcher. His work focuses on absorber materials with narrow band gap for the bottom layer of tandem solar cells and on printed compound solar cells.

Seigo Ito received his PhD from the University of Tokyo with a thesis that was the first to discuss Grätzel-type dye-sensitized solar cells in Japan. After his PhD, he worked at Osaka University in Japan and at the Swiss Federal Institute of Technology in Lausanne. He is currently a professor and his research focuses on new printable, silicon, and extremely thin absorber solar cells.

References

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