Speeding up production of materials for solar energy applications

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A flame aerosol reactor process that simplifies fabrication of photocatalytic films could prove attractive to industry.

One of the major obstacles to widespread harvesting of solar energy is the high production cost of silicon-based solar cells, the dominant technology today. Low-cost alternatives include dye-sensitized solar (DSS) cells and photocatalytic water-splitting (PWS) cells. Both use a wet photoelectrochemical process to convert the energy in sunlight to a more usable form: in the case of DSS cells electricity, and in the case of PWS cells hydrogen gas. To use light most efficiently to promote a desirable photochemical reaction, both alternatives employ a photocatalyst, such as TiO$_2$, typically immobilized as a film.

Fabrication of photocatalytic films has been an area of active research for several decades, and a number of techniques have been developed. But most of them involve multistep processes that can take from several hours to a day to complete. They are not well suited to the inexpensive industrial scale-up that would be required for widespread implementation.

We have recently developed a well-controlled high-temperature gas-phase process for synthesizing TiO$_2$ films in a single step. The process is based on a flame aerosol reactor (FLAR) that is simple and inexpensive. It consists of four mass flow controllers to regulate process gases, a standard bubbler to deliver a Ti precursor, a metal tube that acts as a burner, and a water-cooled substrate holder. Figure 1 shows the FLAR in operation.

TiO$_2$ particles are formed in a premixed methane-oxygen flame by thermal oxidation of the Ti precursor, titanium tetraisopropoxide (TTIP). These particles are then deposited from the hot flame region onto the water-cooled substrate via thermophoresis. The substrate temperature can be controlled by process parameters to facilitate particle restructuring while ensuring that the film has the desired crystalline phase (anatase). Typical deposition times for obtaining highly photoactive films are on the order of 10 min.

The films synthesized by our FLAR exhibit two different morphologies. The first is a well-sintered columnar-like structure. The second is a particulate morphology that consists essentially of TiO$_2$ powder caked onto the substrate. These two morphologies are illustrated by the side-view scanning electron micrograph (SEM) images in Figures 2 and 3. The film morphology is controlled by the TTIP feed rate, through its influence on particle sintering dynamics. These dynamics, for a constant substrate

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As generated, the films are photoactive and split water on exposure to UV light. The morphology affects the water-splitting performance. For films produced under similar FLAR conditions, sintered columnar films have an order of magnitude higher water-splitting efficiency compared with particulate films. For sintered columnar films, hydrogen conversion efficiencies of 5% are readily obtained without post-processing.

In summary, we have developed a simple, inexpensive, scalable method of depositing photocatalytic films for solar energy applications in about 10 min. We have applied our reactor to the synthesis of TiO₂ films. However, in principle it could be used to make many metal-oxide photocatalytic films for which suitable precursors exist (for instance, we recently synthesized Fe₂O₃ films). With further optimization of the FLAR process, the 5% hydrogen conversion efficiency could likely be pushed well beyond 10%. A systematic report of the relationship between process parameters and film morphology is currently in press. Unpublished data can be found on our website.

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**References**