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Scalable Indium Phosphide Thin-Film Nanophotonics Platform for Photovoltaic and Photoelectrochemical Devices

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Introduction

Recent developments in nanophotonics have provided a clear roadmap for improving the efficiency of photonic devices through control over absorption and emission of devices. However, it is often challenging to physically create the nanophotonic designs required to engineer the optical properties of devices. Here, we present a platform based on crystalline indium phosphide that enables thin film nanophotonic structures with physical morphologies that are impossible to achieve through conventional state-of-the-art materials growth techniques. Here, nanostructured InP thin-films have been demonstrated on non-epitaxial alumina inverted nanocone (i-cone) substrates *via* a low-cost and scalable thin-film vapor-liquid-solid (TF-VLS) growth technique, which has been demonstrated to produce high-quality, large grain size (>100 μm) III-Vs on non-epitaxial substrate. Through this approach a wide variety of nanostructured film morphologies are accessible using only control over evaporation process variables. Critically, the as-grown nanotextured InP thin films demonstrate excellent optoelectronic properties, suggesting this platform is promising for future high performance nanophotonic devices.

Fabrication Process of InP

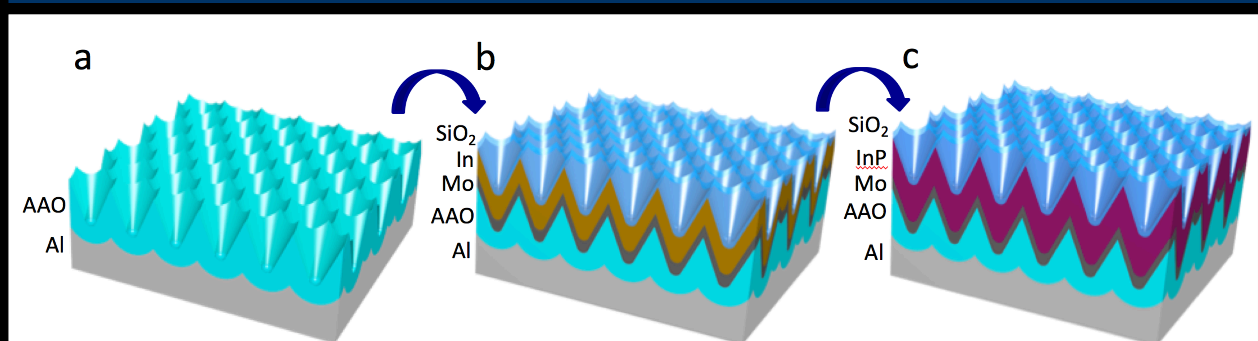

Figure 1. Schematic synthesis process of nanostructured InP thin films. (a) AAO i-cone substrate. (b) AAO i-cone substrate with Mo, indium, SiO_x films. (c) The i-cone InP thin films grown on AAO i-cone substrate.

- Indium films are evaporated onto the i-cone structures in the desired morphology, followed by a high temperature step that causes a phase transformation of the indium into indium phosphide, preserving the original morphology of the deposited indium.

Indium Thin Films

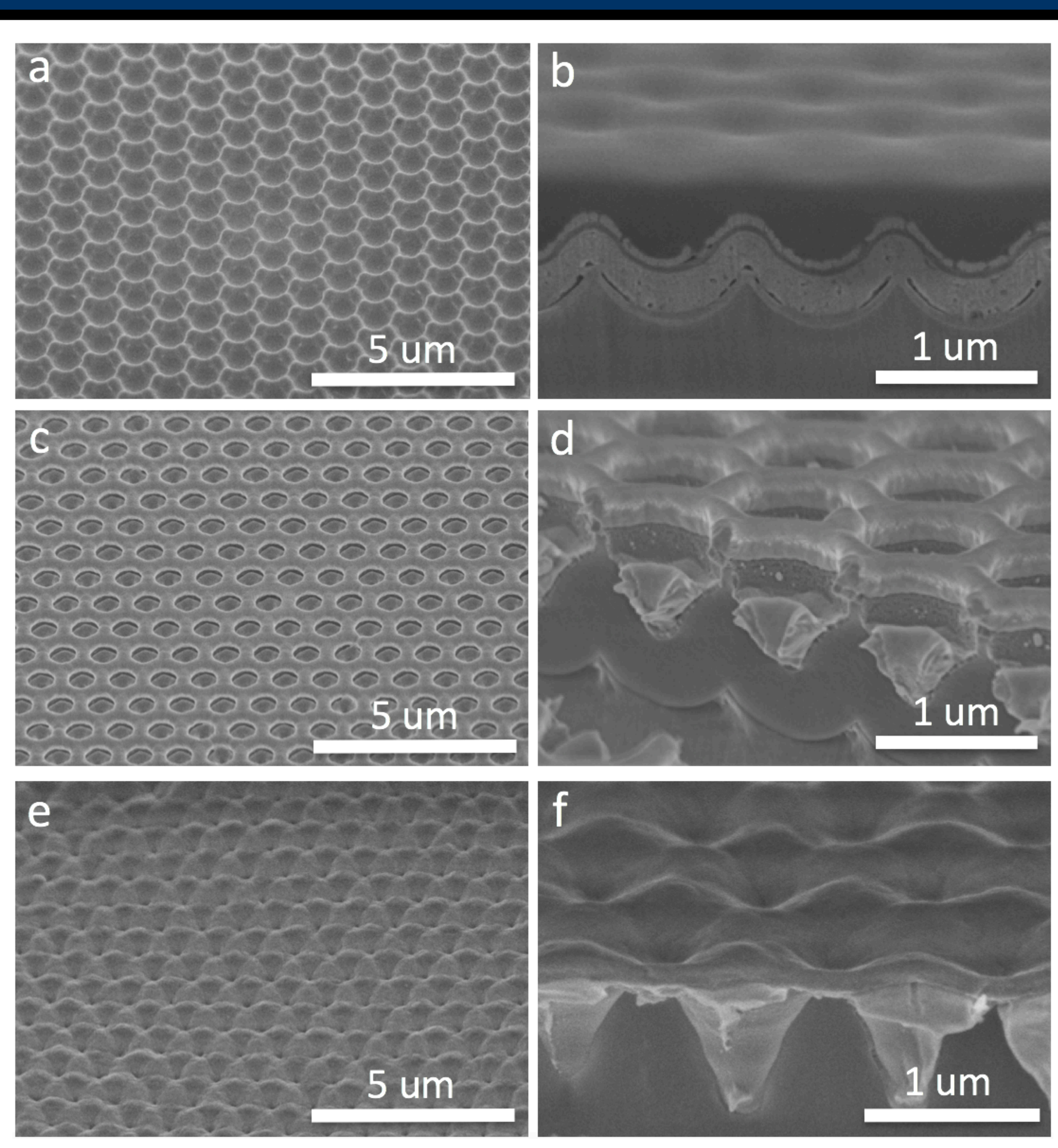

Figure 2. SEM images of indium thin films with different morphologies on various i-cone substrates. (a, b) Conformal i-cone thin films on 250 nm deep i-cone substrates. (c, d) Split resonant structures on 500 nm deep i-cone substrates. (e, f) Independent top and bottom surfaces on 1 μm deep i-cone substrates.

- It's critical to investigate the range of indium film morphologies possible to achieve, since the resulting morphology of the InP thin films are dictated by the deposited indium.

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Indium Evaporation Conditions

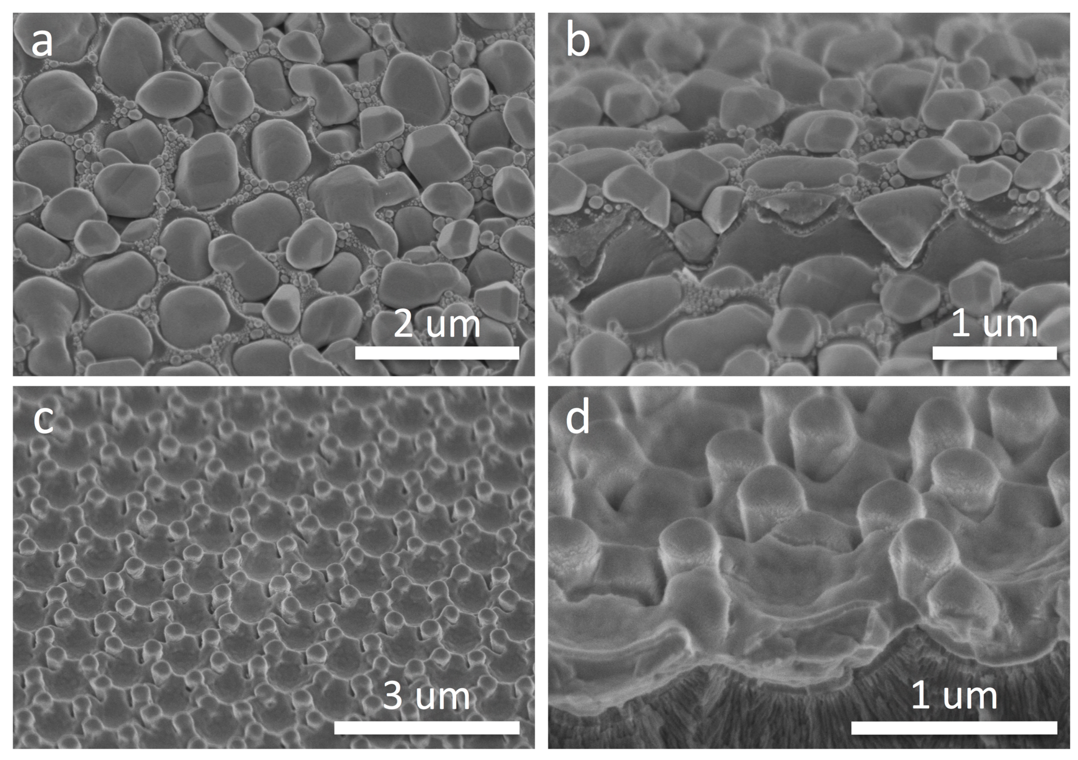

Figure 3. SEM images of indium evaporated on i-cone substrates with various evaporation conditions. (a, b) 200 nm thick indium evaporated at room temperature with 4 Å/sec evaporation rate on 500 nm deep i-cone substrates. (c, d) 500 nm thick indium evaporated at 120 K with 30 Å/sec evaporation rate on 250 nm deep i-cone substrates.

- The varied indium morphologies were achieved by tuning the (i) substrate temperature during evaporation, and (ii) the evaporation rate. The indium thin films as shown in Figure 2 were achieved at 120 K with 5 Å/sec evaporation rate.

Various InP Nanostructures

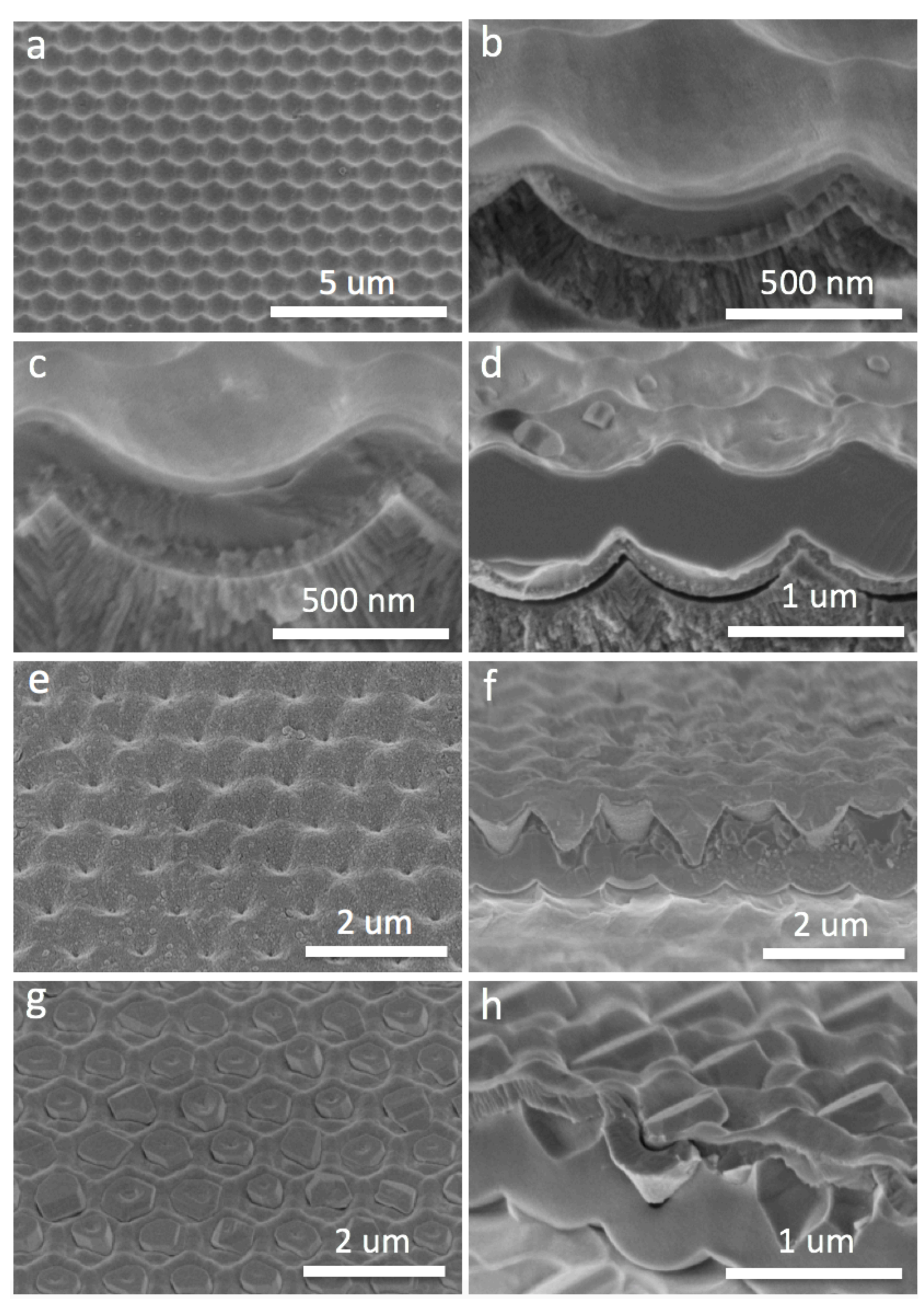

Figure 4. SEM images of nanostructured InP thin films. (a, b, c, d) Conformal ultra-thin InP nanostructured films with tunable thicknesses. (e, f) Touching cone-shaped InP nanostructures. (g, h) InP hybrid nanostructures.

- These conformal structures have been previously shown to be significant in light trapping for ultra-thin photovoltaics, but always used amorphous or nanocrystalline semiconductors. This work demonstrates a potentially high performance semiconductor directly grown in this morphology, which will contribute to development of low-cost high performance devices.

Reference & Contact Information

- Reference: Q. Lin, R. Kapadia, *et. al.*, *ACS Nano*, 2017, *11*, 5113-5119.

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Material Quality of InP

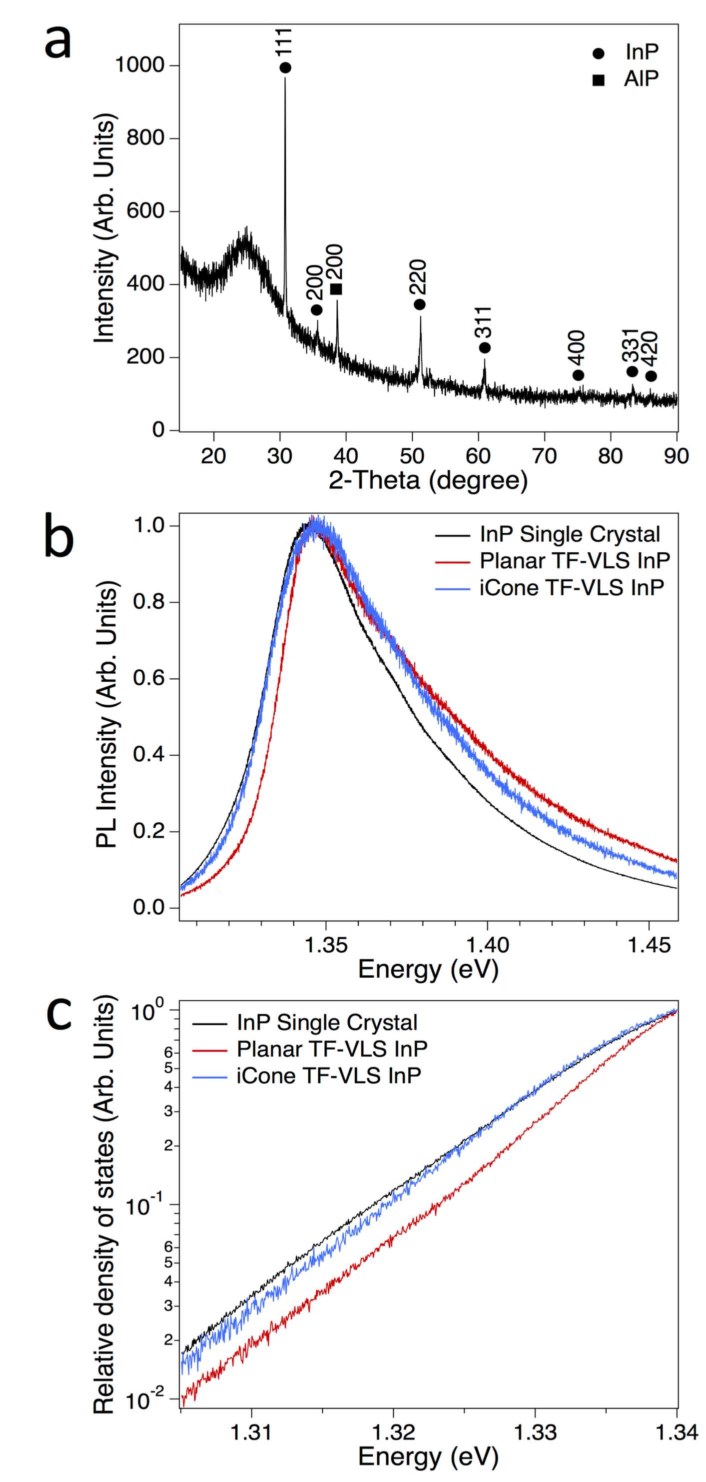

Figure 5. Material quality characterization of nanostructured InP thin films. (a) XRD spectrum of 500 nm thick i-cone InP films. (b) SSPL curves of i-cone TF-VLS InP films, planar TF-VLS InP films, and a single crystalline n-type InP wafer. (c) Relative density of states of i-cone TF-VLS InP films, planar TF-VLS InP films, and a single crystalline n-type InP wafer.

- The XRD spectrum provides the structural evidence for presence of slightly textured zinc blende InP thin films.
- The nanostructured InP thin film exhibits an SSPL peak position of 1.347 eV and FWHM of 0.049 eV, which are similar to the single crystalline reference.
- The semilog inverse slope of the density of states is related to the Urbach tail parameter, which indicates the band edge sharpness arising from crystal defects, thermal vibrations and charged impurities.

Luminescence Yield

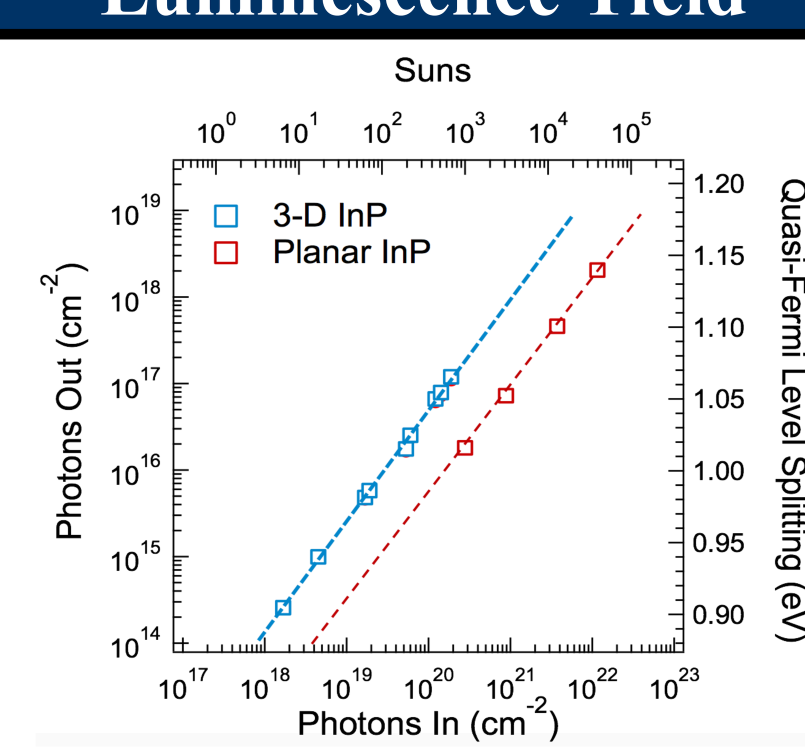

Figure 6. Power-dependent PL emission intensities and quasi-Fermi level splitting of comparable TF-VLS planar and nanostructured InP thin films.

- The nanostructured InP thin film shows an increase of emitted photons and quasi-Fermi level splitting compared to TF-VLS planar counterpart.
- As high quality photovoltaic devices have been made from planar TF-VLS InP, this platform could be used to further improve the quality of those cells.