Reducing Shading Effects in CPV Solar Cells with Advanced Contact Finger Design

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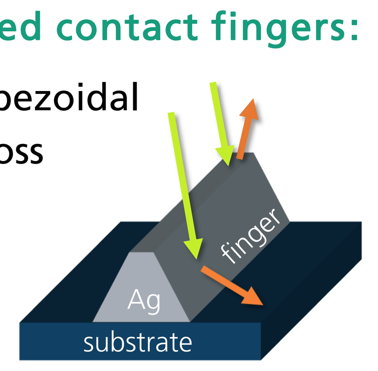
Introduction

- **Motivation:** Reducing finger shading losses in III-V solar cells [1]
- **Goal:** Deflecting light from dedicatedly shaped fingers into active cell area
- Two approaches:

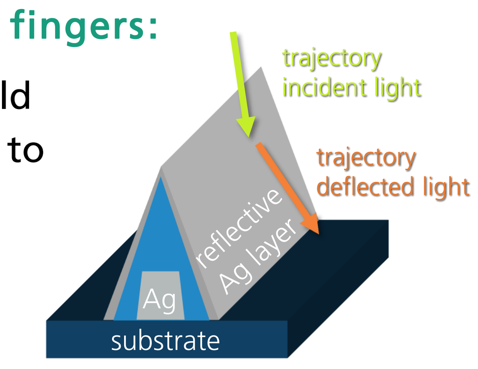
1. Optimized contact fingers:

With trapezoidal finger cross section



2. Cloaked metal fingers:

Polymeric scaffold with Ag coating to cloak the finger



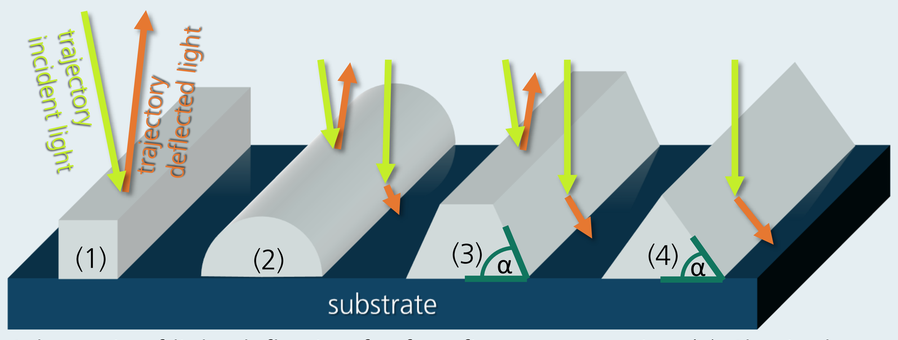
Summary

- Two approaches to reduce shading caused by contact fingers in solar cells:
  1. Optimizing finger cross section to a trapezoidal form to partially redirect incident light. **Shading reduction of 23 %**
  2. Introducing cloaked metal fingers (CMF) with a triangular cross section for efficient light redirection. **Shading reduction of 60 %**
- These approaches are promising pathways to increase the performance of high efficiency multi-junction concentrator cells.

1. Optimized Contact Fingers

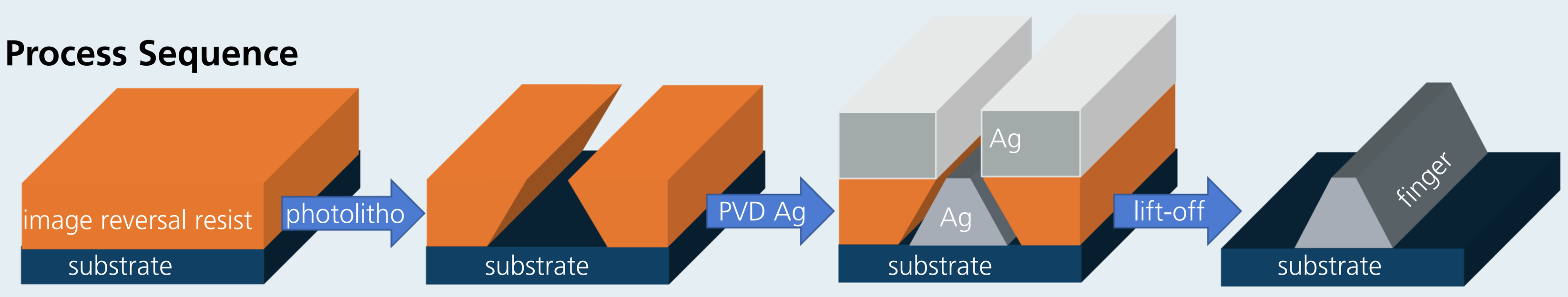
Concept

- Light redirections depend on geometrical shape of the finger
- Most suitable cross section geometries:
  - Trapezoidal (small top width): Realizable by photolithographic (PL) masking and physical vapor deposition (PVD) metallization
  - Triangular: Ideal, yet technically hard to implement



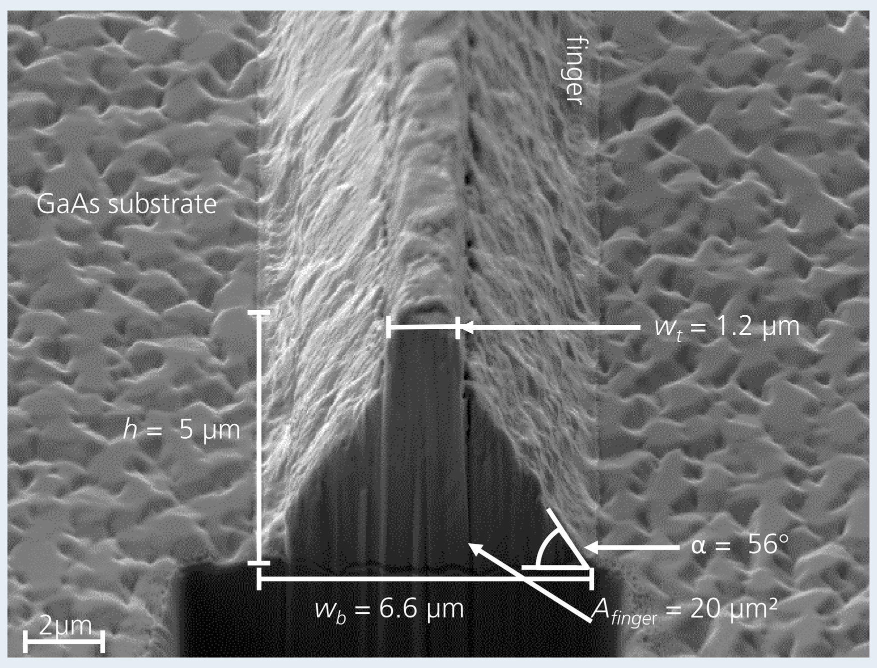
Schematic of light deflection for four finger geometries: (1) Classic shape from photolithography (PL) processing, (2) shape from electro-plating (3) optimized contact fingers (4) e.g. cloaked metal fingers.

Process Sequence

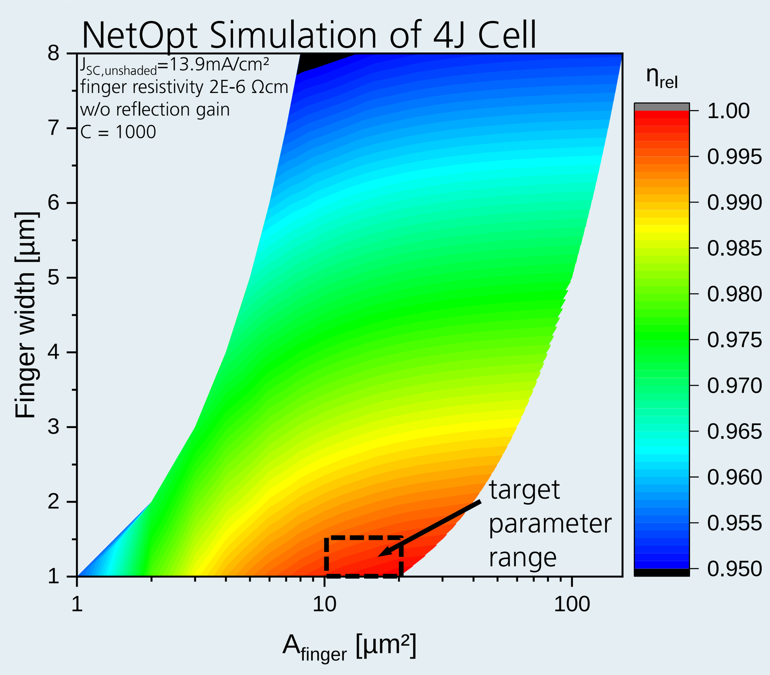


Schematic sketch of the process sequence: A photoresist is used to create narrow openings which are metallized using physical vapor deposition (PVD). The excess Ag is removed in a lift-off process. While the process sequence is used for common III-V solar cell metallization, for the optimized geometries the photolithographic mask was optimized by variating parameters such as baking temperature, exposure spectrum and exposure gap.

Characterization: Scanning Electron Microscope (SEM) and Simulation



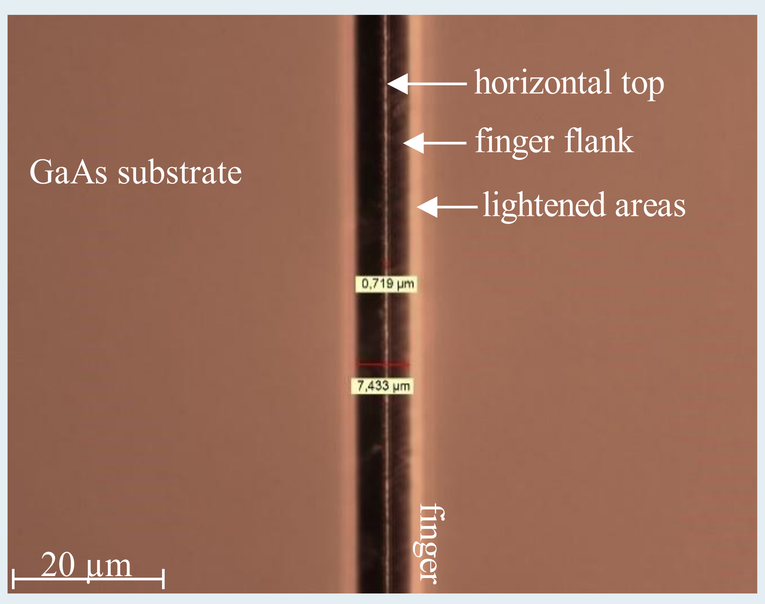
Scanning electron microscope (SEM) images of achieved finger cross section also showing the achieved geometric parameters: Width top w_t, width bottom w_b, height h and cross section area A_{finger}



Simulation results of maximal conversion efficiency (η_{rel}) in dependence on finger cross section area (A_{finger}) and finger width at a concentration C = 1000. The target area for the ideal finger shape is marked.

Results

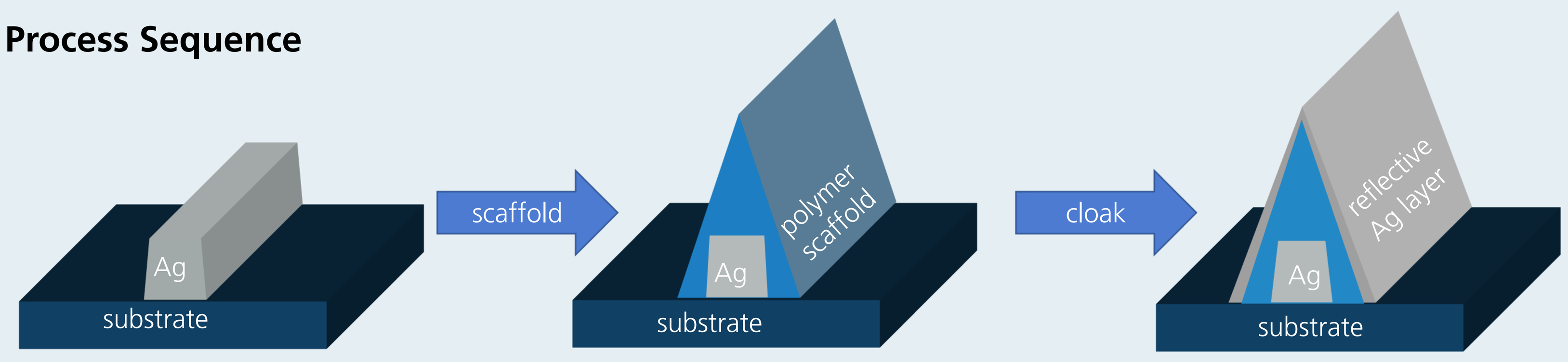
- Simulations[2] reveal optimal finger conditions for highest conversion efficiency: top width <1.5 µm and cross-sectional area >10 µm².
- Iterative experimental optimization achieves superior finger geometries surpassing target parameters.
- Microscopic images provide quantitative proof of incident light redirection to active cell areas.
- At the cell level[1], the optimized fingers **reduce shading by 23 %** compared to reference fingers (3 µm top width, 6 µm bottom width).



Microscopic image of an optimized finger (top view) quantitatively showing the effects of the deflected incident light from the finger flanks onto the substrate.

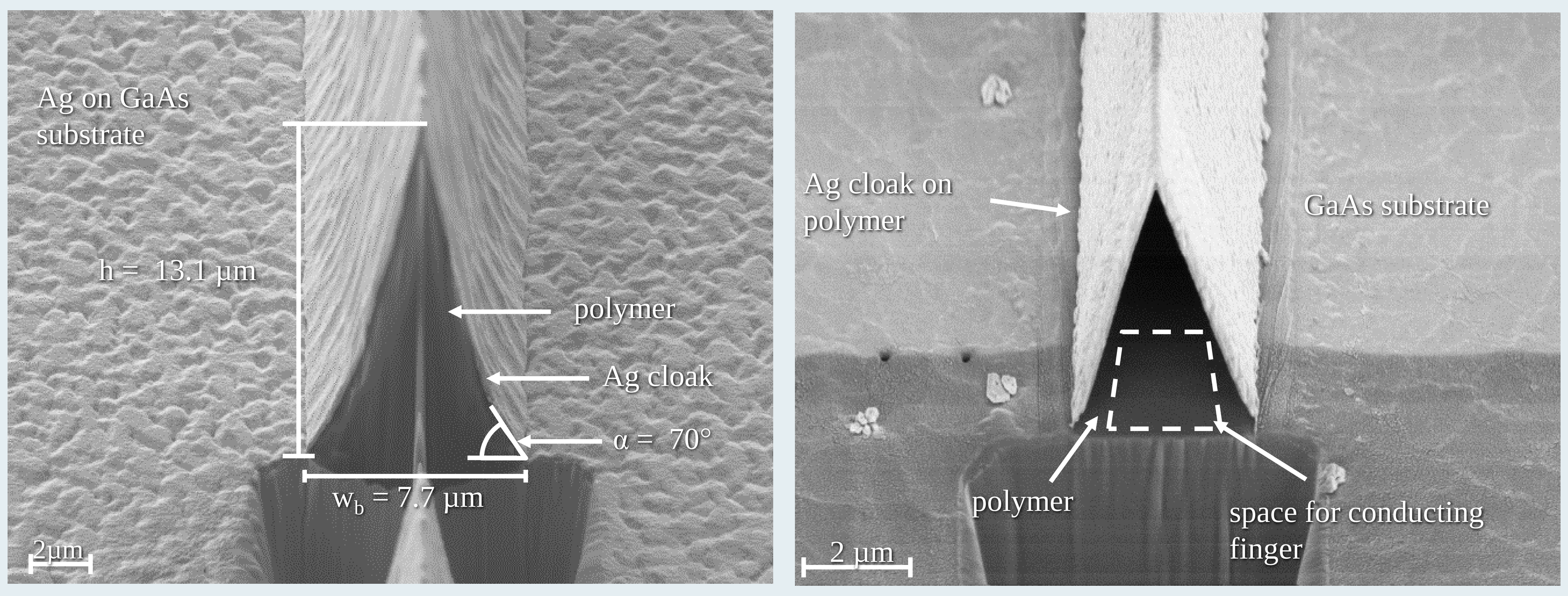
2. Cloaked Metal Fingers (CMF)

Process Sequence



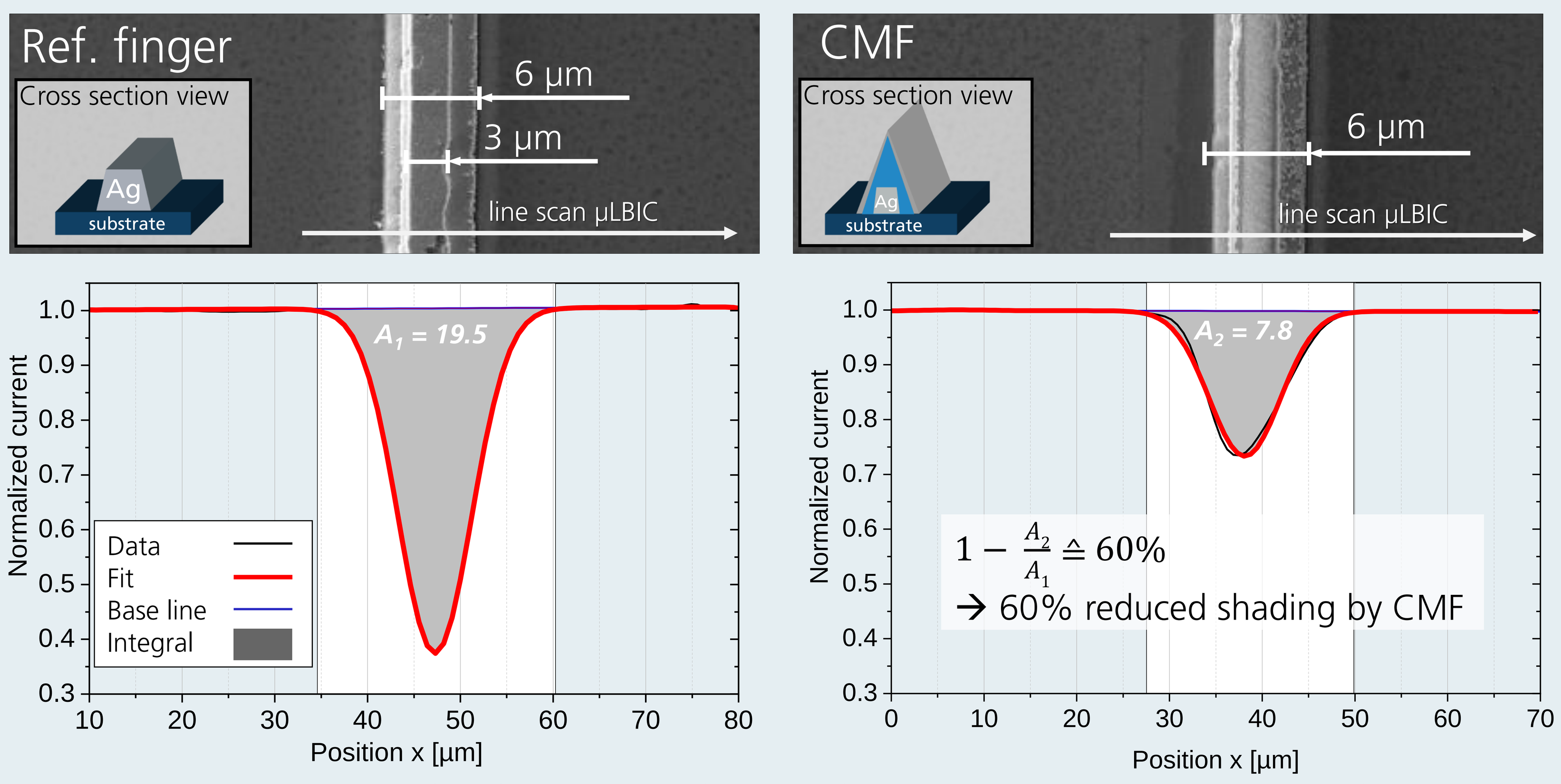
Schematic process sequence for the cloaked metal fingers (CMF). Showing the required elements needed (blue arrows) to create the desired structure and the cross sections of the incremental build-up of the sample.

Characterization: Scanning Electron Microscope (SEM)



*Scanning electron microscope (SEM) images of achieved CMF cross section on test structures. The image on the left shows the CMF with ideal dimensions: Width top w_t, Width bottom w_b, height h, and the steep flank angle **α**. The image on the right shows a significantly smaller CMF in its final state also indicating the area for a conducting finger with A_{finger} = 4 µm²*

Characterization: Micro-light Beam Induced Current (µLBIC) [3]



Micro-light beam induced current (µLBIC)³ measurements (bottom row) and the according SEM images as top view (top row) for a reference finger without application of CMF (left) and the measurement for an identical contact finger covered with the CMF (right). For the µLBIC measurement the measuring laser was moved perpendicular to the cross section of the finger as indicated in the SEM images.

Results

- Proof of concept: Complex microstructures built with a polymeric scaffold, coated with silver for redirecting light onto the active cell area.
- Resulting cross-sections: Triangular with steep angles, optimizing reflection properties.
- µLBIC measurement proof that CMFs **reduce shading by 60 %** compared to reference fingers (3 µm top width, 6 µm bottom width)

[1] Lackner D, Höhn O, Walker AW, et al. Status of Four-Junction Cell Development at Fraunhofer ISE. E3S Web Conf. 2017;16:3009. doi:10.1051/e3sconf/20171603009.
[2] Steiner M, Philipps SP, Hermle M, Bett AW, Dimroth F. Validated front contact grid simulation for GaAs solar cells under concentrated sunlight. Prog Photovolt: Res Appl. 2011;19(1):73-83. doi:10.1002/pip.989.
[3] Breitwieser M, Heinz FD, Büchler A, et al. Analysis of solar cell cross sections with micro-light beam induced current (µLBIC). Solar Energy Materials and Solar Cells. 2014;131:124-128. doi:10.1016/j.solmat.2014.05.002.

Find all Fraunhofer ISE contributions here

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