Rapid and Scalable Fabrication of Si Microfunnel Arrays Using Nanosecond UV-Laser and Selective HNA Etching

A. Chowdhury, D. Kim*, and H. Yoon
Department of Electrical and Computer Engineering, University of Utah
Salt Lake City, UT 84112, USA (*donggeon.kim@utah.edu)

Perforated Si microstructures are promising for dual-function photovoltaic (PV) devices, as their tunable three-dimensional (3D) geometry allows color-neutral daylight transmission while retaining reliable power generation [1]. Established fabrication techniques, such as deep reactive ion etching (DRIE) and metal-assisted chemical etching (MACE), provide control over optical transmission and device performance. However, the use of photolithography and vacuum-intensive processing presents challenges for low-cost and large-scale manufacturing.

Here, we report a maskless fabrication approach to form Si microfunnel arrays by combining UV-laser microdrilling and isotropic HNA wet-etching ($HF/HNO_3/CH_3COOH$) using a SiO_2 cap layer as a etch modulator. This etching converts the as-drilled microholes into well-defined microfunnel profiles without lithographic alignment or dry etching in a high-vacuum environment. After UV microdrilling, we performed isotropic HNA etching by varying conditions of: (i) HNA concentration ($HF/HNO_3/CH_3COOH$), (ii) etch duration (30 s to 10 min), and (iii) hydrodynamic conditions (static vs. stirred; up to 3,000 rpm)

We correlate the fabrication parameters with resulting microfunnel diameters, half-angle, and sidewall morphology. Distinct etching regimes are identified in which agitation improves etch uniformity by suppressing localized bubble adhesion and transport limitations. Optical characterization of the microfunnel arrays confirm that the integrated laser/HNA process allows tunable transmission via array pitch and final opening size, while providing desirable scattering and reflectance behavior due to sidewall smoothing and microfunnel tapering [2].

Overall, the laser microdrilling and HNA etching strategy offers a scalable and low-complexity pathway for fabricating tunable 3D optoelectronic architectures. We further discuss etching kinetics and and morphology-control mechanisms, supporting optimized translucent Si PV design.

References

[1] J. Park, K. Lee, J. Lee, D. Kim, M. Lee, and K. Seo, "All-back-contact neutral-colored transparent crystalline silicon solar cells enabling seamless modularization," *Proc. Natl. Acad. Sci.*, **121**, e2404684121 (2024).
[2] A. Chowdhury and H. Yoon, "Translucent Si solar cells patterned with pulsed ultraviolet laser beam," *Adv. Energy Sustain. Res.* 2400147 (2024).
[3] Acknowledgments: The authors acknowledge J. Ojewia, T. Kim, A. Mamun for their assistance with sample preparation.

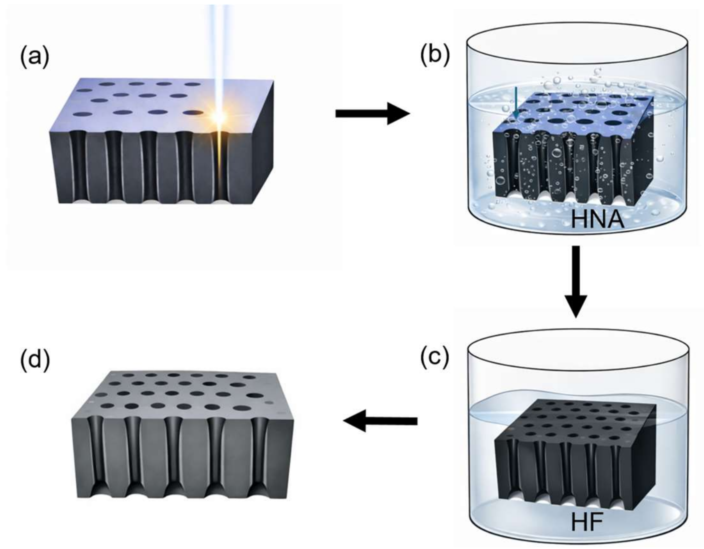

Figure 1. Schematic showing the maskless fabrication process for Si microfunnel arrays: (a) UV-laser microdrilling (b) HNA ($HF/HNO_3/CH_3COOH$) wet etching to clean the laser-drilled microholes; (c) remove the sacrificial SiO_2 layer; and (d) final microfunnel array structure.

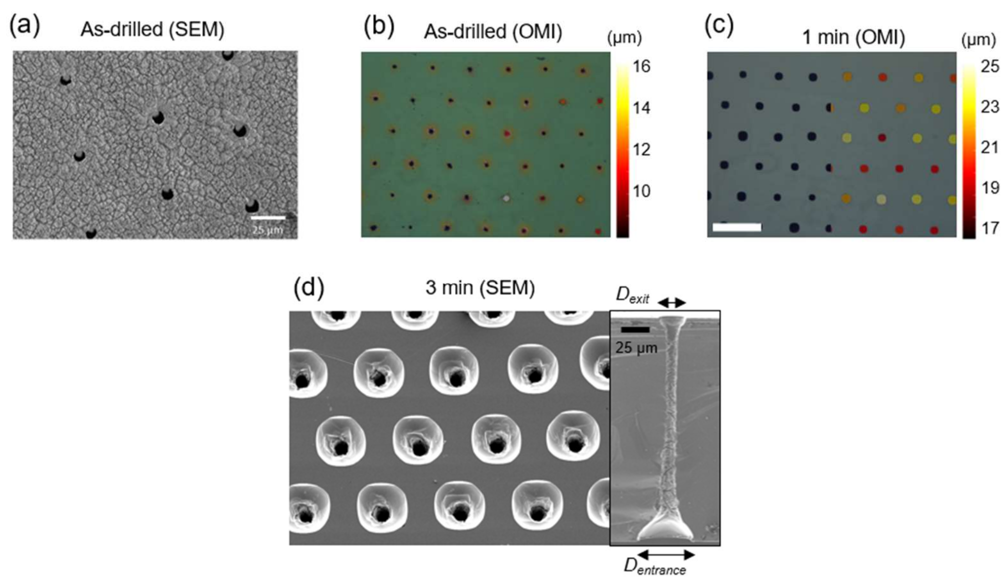

Figure 2. (a) Scanning electron microscopy (SEM) image of the as-drilled Si microholes, (b) Optical microscopy image (OMI) of the microholes covered with a SiO_2 cap layer, (c) OMI after 1 min of HNA etching, and (d) SEM image after 3 min of HNA etching, with an inset showing a cross-sectional view.