Ultrahigh Aspect Ratio Silicon Structures for Energy Storage Applications

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Integrated ultrahigh aspect ratio structures at both the micro and nanoscales are important for a wide variety of applications in areas including energy storage, sensors, drug delivery, and x-ray optics. With the advent of the internet of things (IoT), interest in integrating energy storage onto silicon with energy harvesting and sensors has significantly increased. Silicon is already the materials of choice for the integrated circuits found in every IoT device; however, the efforts to integrate energy storage and/or sensors on a silicon die have been limited.

For energy storage, electrochemical capacitors with cycle lifetimes of many thousands is especially important for off-power-grid IoT devices. Integrated energy storage using porous silicon (P-Si) coated with extended-exposure ALD TiN films (see Fig. 1) have previously been successfully demonstrated [1]. In this work, new ultrahigh aspect-ratio *patterned* P-Si structures (aspect ratio > 500:1) were prepared (see Fig. 2) using metal assisted chemical etching [2]. The aspect ratios are approximately an order of magnitude higher than that achieved using deep reactive ion etching. Coating these structures with ALD films for energy storage applications presents unique challenges. Cross-sectional SEM images were used to examine the penetration depth and show that ALD films can be made to penetrate deep into high aspect ratio structures. Devices prepared with these structures have the potential to provide integrated on-chip energy storage in a compact form factor with minimal packaging.

[1] D. S. Gardner, C. W. Holzwarth III, et.al., "Integrated On-Chip Energy Storage Using Passivated Nanoporous-Silicon Electrochemical Capacitors", Nano Energy (2016), doi: 10.1016/j.nanoen.2016.04.016

[2] C. Chang, A. Sakdinawat, "Ultra-high aspect ratio high-resolution nanofabrication for hard X-ray diffractive optics", Nature Communications 5, 4243 (2014).

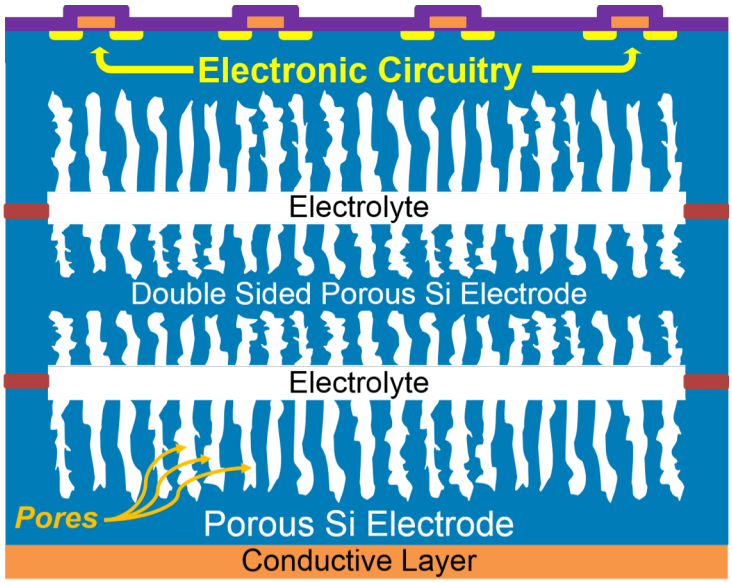

Fig. 1. A stacked porous silicon based electrochemical capacitor using double-sided porous silicon [1].

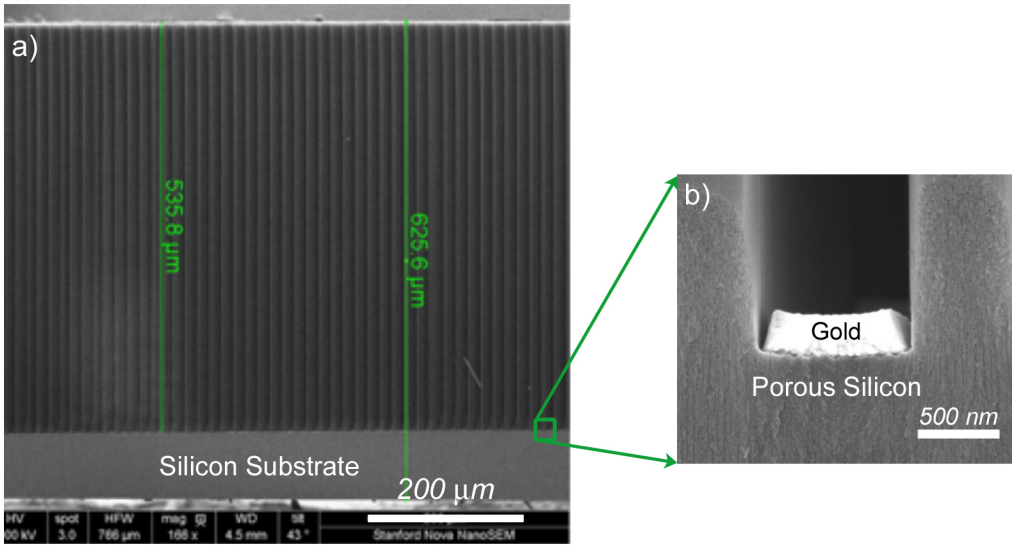

Fig. 2. SEM image of >500:1 aspect ratio patterned P-Si structures. a) Patterned 535 micron deep features in wafer that is 625 microns thick. b) Patterned 1 micron wide gold film at the bottom of the trench with P-Si.