Black Silicon for high-contrast alignment marks fabricated using mask-less Photolithography and optimized Bosch Reactive-Ion Etching

M. Yusuf
Department of Chemical Engineering, Stanford University, Stanford, CA 94305
myusuf@stanford.edu

G. K. Herring, L. T. Neustock, M. A. Zaman, L. Hesselink
Department of Electrical Engineering, Stanford University, Stanford, CA 94305

U. Raghuram, S. Kommera
Stanford Nanofabrication Facility, Stanford University, Stanford, CA 94305

V. Narasimhan
Intermolecular Inc., San Jose, CA 95134

Holographic alignment marks offer great potential for high-precision alignment of micromechanical, optical and nanophotonic structures[1]. We have designed a mark based on the principle of Fresnel zone plates with micron-scale bands of optically “dark” absorptive areas and “bright” reflective areas. Black Silicon (BSi), which encompasses many classes of silicon nanostructures demonstrating broadband, omni-directional absorption for use in applications ranging from solar cells to gas sensors[2], is fabricated in the dark areas, thus producing high-contrast. Methods such as stain etching, electrochemical etching, and reactive-ion etching (RIE)[3] have been studied for the fabrication of BSi. However, the complexity of these fabrication techniques has limited the use of black silicon in practical applications.

In this work, we develop a simple, rapid workflow for selectively patterning macro-scale areas of black silicon on a silicon substrate to fabricate high-contrast alignment marks. Our fabrication method avoids the use of nano-scale masks and extra materials such as metal catalysts, providing an approach that can be easily integrated into a variety of device applications. Using maskless photolithography (Heidelberg MLA 150) and multiplexed reactive-ion etching[4] (PlasmaTherm Deep Silicon Etcher), we perform a comprehensive investigation of the process-structure-property relationship between the etching process conditions, black silicon morphologies, and their light absorption. Different morphologies of black silicon (Figure 1) are fabricated by changing the chamber conditioning, polymer deposition time, etch bias voltage, and the number of deposition cycles. The fabricated structures are subsequently investigated for reflectivity using an in-house optical microscope. Finally, an all-silicon holographic alignment mark using selectively patterned black silicon will be demonstrated.

---

[1] Fay, B., Trotel, J., & Frichet, A. Optical alignment system for submicron x-ray lithography. *Journal of Vacuum Science and Technology*, *16*(6), 1954-1958, 1979. [2] Narasimhan, V. K., & Cui, Y. Nanostructures for photon management in solar cells. *Nanophotonics*, *2*(3), 187-210, 2013. [3] Liu, X., Coxon, P. R., Peters, M., Hoex, B., Cole, J. M., & Fray, D. J. Black silicon: fabrication methods, properties and solar energy applications. *Energy & Environmental Science*, *7*(10), 3223-3263, 2014. [4] Stubenrauch, M., Fischer, M., Kremin, C., Stoebenau, S., Albrecht, A., & Nagel, O. Black silicon—new functionalities in microsystems. *Journal of Micromechanics and Microengineering*, *16*(6), S82, 2006.

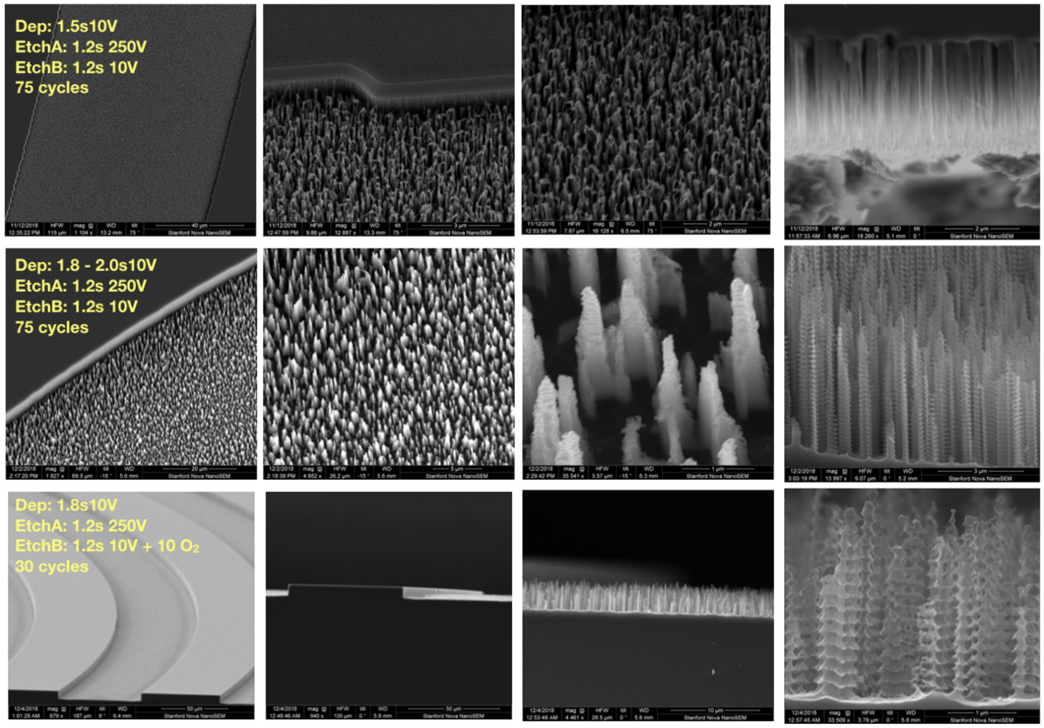

Figure 1: Black Silicon Morphologies: Different morphologies of black silicon are fabricated using Bosch reactive-ion etching (RIE) in the Stanford Nanofabrication Facility (SNF). The Scanning Electron Micrographs (SEM) show the needle-like structures with diameter less than 1 μm. Left: Top view images of the "dark" area (areas of black silicon) and the "white" areas (no etching). Right: Cross-sectional images of the black silicon area.