SAND2022-11542C

Fabrication and Characterization of Large Area Plasmonic Metasurface Lenses

D. Bruce Burckel and Katherine M. Musick
Sandia National Laboratories, P.O. Box 5800 Albuquerque, NM 87185, USA
dbburck@sandia.gov

Abstract: Metasurface lenses are fabricated using membrane projection lithography following a CMOS-compatible process flow. The lenses are 10-mm in diameter and employ 3-dimensional unit cells designed to function in the mid-infrared spectral range.

1. Introduction

As micro/nano fabrication approaches continue to mature, the ability to create complex sub-wavelength structure in a volume has spurred research into metamaterials. The appeal of metamaterials is that the functionality of a volume can be tuned by changing the structure as well as by combining disparate materials on a sub-wavelength scale [1]. Metamaterials offer many promising applications in optical, photonic and acoustic domains. Here we demonstrate the fabrication of metasurface lenses using membrane projection lithography (MPL).

2. Fabrication

Figure 1 shows a schematic diagram of the MPL process. A 1-micron thick low-stress silicon nitride (LSN) layer is deposited on a silicon wafer, followed by a 3-micron thick amorphous silicon (α-Si) layer (A). Reactive ion etching is used to create trenches in the α-Si layer (B), which are subsequently filled with a conformal LSNand etched back to expose the α-Si in the volume of the unit cell (C). A silicon dioxide film is deposited and patterned with the desired unit cell patterns (D). XeF_2 is used to dissolve out the α-Si through the patterned oxide membrane (E) and directional evaporation is used to deposit replicas of the membrane pattern on the vertical sidewalls of the unit cells (F). After liftoff and backside removal, the 2D array is supported by the original LSN membrane (G).

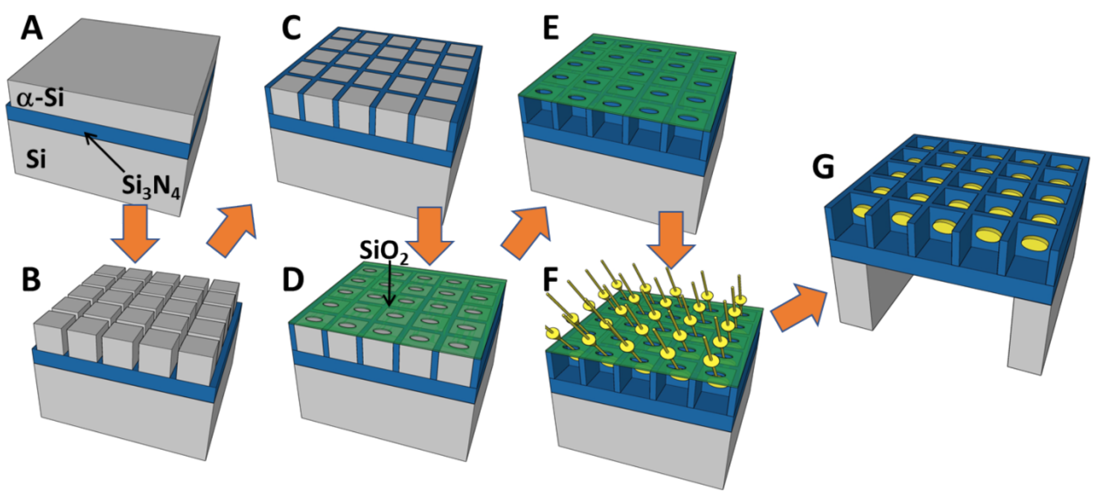

Fig. 1. Schematic process flow for membrane projection lithography.

Figure 2 shows scanning electron microscope (SEM) images of a portion of the array during various stages of fabrication. In this figure, canonical structures are used for the patterns for simplicity. For the lenses, more complicated plasmonic structures designed using a genetic algorithm procedure were used. In 2A, the unit cells are shown after the etch through the α-Si to create the unit cell walls. In 2B, the walls have been filled with LSN. In 2C the oxide has been deposited and patterned. In 2D, XeF2 (a gas phase etch) has been used to remove the a-Si in the center of the unit cells (note – there is a change in pattern from C to D). At this point, the sample is ready for

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

evaporation. Fig 2E shows the results after deposition of the plasmonic inclusion in the unit cell and subsequent liftoff of the patterned membrane.

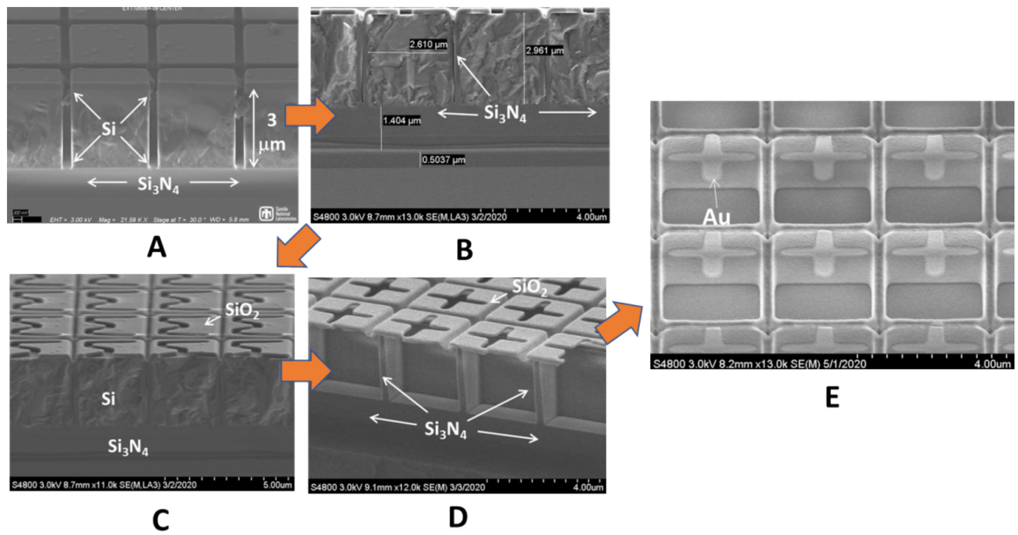

Fig. 2. SEM images of a portion of the array at various stages of fabrication. (A) After α-Si wall etch; (B) After LSN wall fill; (C) after oxide membrane patterning step; (D) XeF_2 cavity evacuation;(E) metal deposition and liftoff.

In this talk we will discuss the fabrication approach in detail and cover the genetic algorithm approach used to design the phase elements for the metasurface lens. Finally, we will present detailed infrared characterization results for the lenses.

3. Acknowledgement

This work was performed, in part, at the Center for Integrated Nanotechnologies, an Office of Science User Facility operated for the U.S. Department of Energy (DOE) Office of Science. This work was performed under the DARPA Extreme Optics and Imaging (EXTREME) program under contract number HR0011726711. Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525. This paper describes objective technical results and analysis. Any subjective views or opinions that might be expressed in the paper do not necessarily represent the views of the U.S. Department of Energy or the United States Government.

4. References

[1] C. M. Soukoulis, and M. Wegener, "Past achievements and future challenges in the development of three-dimensional photonic metamaterials," Nat. Phot. **5**, 523-530, (2011).

[2] D. B. Burckel, J. R. Wendt, G. A. Ten Eyck, A. R. Ellis, I. Brener, and M. B. Sinclair, "Fabrication of 3D metamaterial resonators using self-aligned membrane projection lithography.," Adv. Mater. **22**, 3171–3175, (2010).

[3] D. B. Burckel, J. R. Wendt, G. A. Ten Eyck, J. C. Ginn, A. R. Ellis, I. Brener, and M. B. Sinclair, "Micrometer-scale cubic unit cell 3D metamaterial layers," Adv. Mater. **22**, 5053–5057 (2010).

[4] D. B. Burckel, P. J. Resnick, P. S. Finnegan, M. B. Sinclair, and P. S. Davids, "Micrometer-scale fabrication of complex three dimensional lattice + basis structures in silicon," Opt. Mater. Express **5**, 2231, (2015).

[5] D. B. Burckel, S. Campione, P. S. Davids, and M. B. Sinclair, "Three dimensional metafilms with dual channel unit cells," Appl. Phys. Lett.. **110**, (2017).

[6] D. B. Burckel, M. Goldflam, K. M. Musick, P. J. Resnick, G. Armelles, and M. B. Sinclair, "Coupling between plasmonic and photonic crystal modes in suspended three-dimensional meta-films," Opt. Express **28**, 10836, (2020).