Metalized ceramic corrugated films as lightweight space-based microwave reflectors

Victoria Fethke[1], Mohsen Azadi[2], Matthew F. Campbell[1], Igor Bargatin[1]

1. Department of Mechanical Engineering and Applied Mechanics, University of Pennsylvania
2. Singh Center for Nanotechnology, University of Pennsylvania. azadi@seas.upenn.edu

A major challenge in design of space antennas is creating a reflector that is lightweight, deployable, can sustain high acceleration forces, and is wrinkle-free [1]. Though much progress analyzing different concepts and materials has been made, we are unaware of any existing reflector that can circumvent the need for a bulky tensioning frame [2-5].

We report metalized mechanical metamaterial reflectors that are made of few-100 nm thick aluminum oxide covered by ~ 10 nm thick metal films, such as aluminum. Importantly, these films' corrugated design prevents them from wrinkling or tearing relative to traditional planar membranes. Preliminary optical simulations using film properties from available literature [6,7] reveal near-unity reflectivity for aluminum thicknesses of above 10nm on a 500 nm alumina core at both normal and off-angle incidences (Figure 1). Furthermore, the areal density of these reflectors is less than 2 g/m^2. The robustness, reflectivity, and low density of our films make them ideal candidates for in-space parabolic reflectors with minimal supporting frames.

To increase the scalability of the final reflector, we leverage a honeycomb corrugated pattern to increase the bending stiffness of thin films by several orders of magnitude, making them wrinkle-free [8]. Moreover, by introducing a hole in the middle of each hexagon, we allow for fast release of the final product, regardless of the deployable size. A CAD rendering of this hexagon unit cell with the release hole is shown in Figure 2. We manufacture cm-scale tiles from these individual unit cells that will ultimately comprise a m-scale space-deployed reflector. Fabrication starts by patterning a Si wafer via photolithography and RIE. We remove the remainder of the resist via O_2 plasma and deposit the aluminum oxide core and aluminum film via ALD and PVD sputtering, respectively. We then pattern the release holes in a second lithography step. Using Cl_2/BCl_3 chemistry in an ICP RIE tool we etch through the Al_2O_3/Al stack and expose the Si mold, then strip the remainder of the photoresist is by O_2 plasma and sonication in a heated remover bath. The tiles are cut to the desired size using laser micromachining and placed in 3D printed fixtures for a final cyclic XeF_2 gas etching step to suspend the film over the substrate.

1. Chandra, M. *et al*. Advances in Space Research, 68, 3749–3764 (2021)
2. Gaspar, J. et al., in 48th AIAA Structures. Structural Dynamics, and Materials Conference, 1832. (2007)
3. Cadogan, D. 'Rigidization Mechanisms And Materials', pp. 257–279. (2001)
4. Kumar, S., Upadhyay, S.H., Proceedings of ICOVP 2015 December 14–17, (2015). IIT Guwahati, India
5. Nakamura, K. et al. 3rd AIAA Spacecraft Structures Conference, pp. 1–12. (2016).
6. Ordal, M.A. *et al*, Applied Optics, Vol 24, No 24 (1985)
7. Rajab, K.Z. *et al*, J. Micro. And Elect. Pack. 5, 101-106 (2008)
8. Davami, K. *et al*, Nat. Commun. 6:10019 (2015)

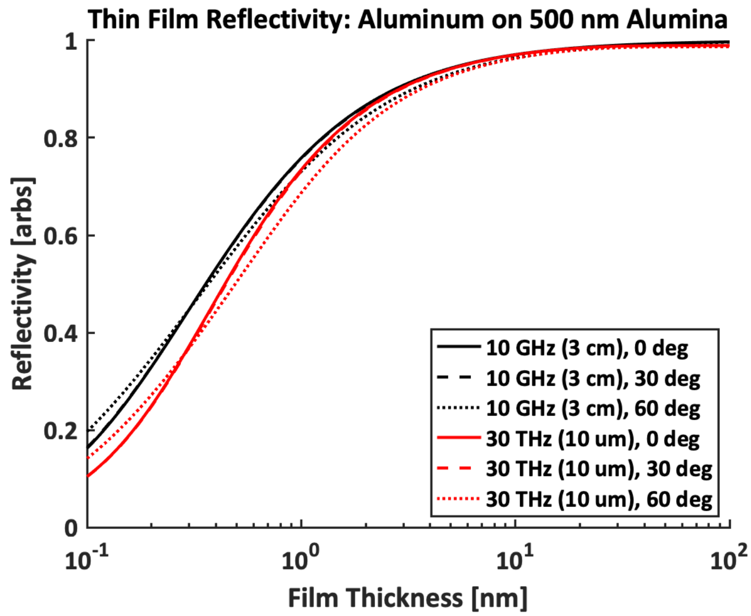

Figure 1. reflectivity vs Al film thickness at various reflection angles and wavelengths.

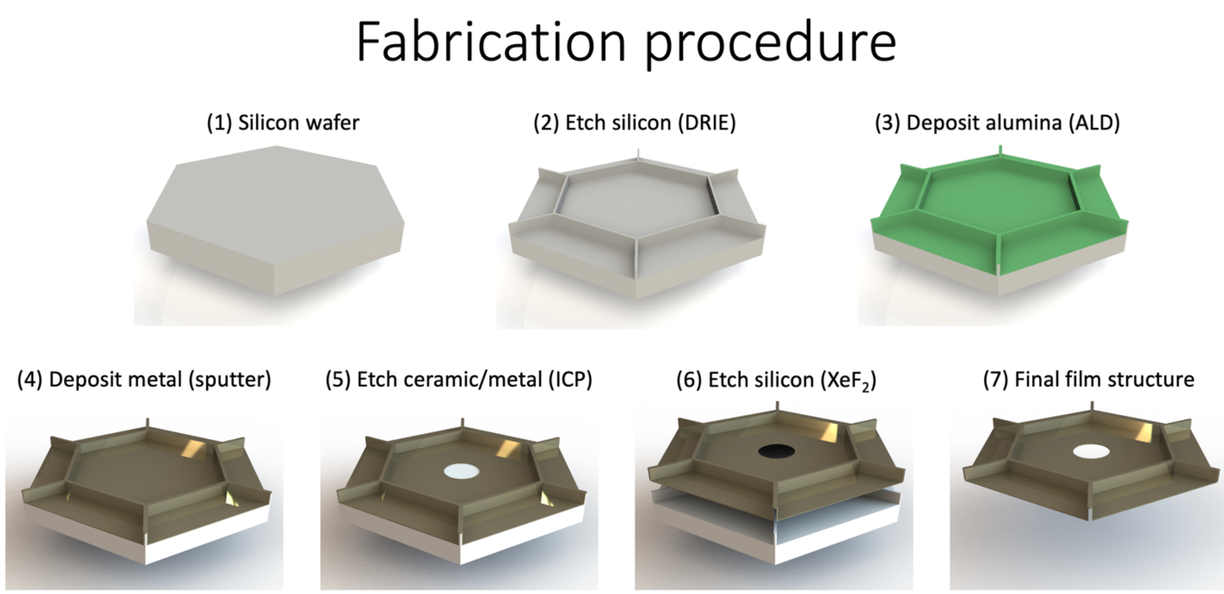

Figure 2. Fabrication process of unit cell