1. Student name: Nicolas Garcia

2. Faculty mentor name: Prof. Jonathan Chisum

3. Project title: Microperforation of Silicon Wafers for Variable Permittivity

4. Briefly describe any new skills you acquired during your summer research:
Most of my work was in the clean room where I processed silicon wafers. My process included cleaning, photoresist application, photolithography, development, and Bosch etch. As a result, I'm familiar with general photolithography, etch, and characterization techniques for microfabrication applications.
Outside the clean room, I became proficient designing photolithography masks in L Edit design software and running structural physics simulations in COMSOL Multiphysics software.
Finally, I studied Latex for documentation purposes.

5. Briefly share a practical application/end use of your research:
The variable permittivity structures we're creating will be found in high frequency electronics. Most notably, we plan to create lenses/antennae for 5G wireless technologies.

This research was a proof of concept for geometrically perforated silicon wafers. Our goal is to apply perforated silicon as an artificial dielectric, so called because the structural features determine the effective permittivity above a minimum wavelength. By perforating a silicon wafer, we can reduce the wafer's effective permittivity closer to that of air. Note the effective term; this process does not alter the intrinsic permittivity of silicon, only the average permittivity of the structure as seen by a large enough wavefront. In order for this method to be effective, the perforations and their spacing must be smaller than the guided target wavelength. This constraint guarantees that waves will not interact with individual perforations and the wavefront "sees" a weighted average of the two permittivities. This average permittivity is determined by the silicon-air ratio, which is in turn determined by the size of the perforations.

For a target frequency of 60GHz, the perforations and their spacing must be less than 200 microns. Because there are no conventional fabrication techniques on this scale, it's necessary to machine the wafers in a clean room. My primary task was working through our microfabrication process and analyzing the resulting wafers. Before the process could be tested, I had to choose a suitable maximum perforation size for testing – if the perforations are too large, the structure lacks suitable silicon and will disintegrate. Using COMSOL Multiphysics software, I ran structural simulations to determine an adequate perforation size. With these details, I then designed the photolithography mask using L Edit software. I proceeded to the clean room where I cleaned, exposed (with my new mask), and developed the sample wafers before subjecting them to a Bosch etch process. The Bosch process is an anisotropic etch process and so maintains vertical sidewalls in each etch; this is essential to making clean perforations.

I was successful in that I produced multiple wafers that were completely perforated with varying geometries and sizes. However, characterization with the Confocal 3D microscope and the Scanning Electron Microscope revealed moderate undercut in the etched perforations. This indicates that our specific Bosch process needs to be tweaked. Fortunately, characterization also revealed that the perforation sidewalls are not significantly scalloped – that is, the perforations are smoother than anticipated. Aside from the imperfect Bosch etch component, the microfabrication process is acceptable for our purposes.

Going forward, we'll need to perfect our etch process. From there, we can produce a large number of perforated structures and test their altered permittivities. These structures can then be made into high frequency lenses and antennae.

Presentation:
Microperforation of Silicon Wafers for Variable Permittivities