Heat Transfer Through Nanogaps

Josef Velten
Materials Science and Engineering, Illinois Institute of Technology

NNIN REU Site: Nanoscience @ UNM, University of New Mexico
NNIN REU Principal Investigator: Dr. Kevin Malloy, Center for High Technology Materials, University of New Mexico
NNIN REU Mentor: Ryan Martin, Department of Electrical Engineering, University of New Mexico
Contact: claverjoe@gmail.com, malloy@unm.edu

Abstract:

Traditionally, heat transfer is modeled into three basic categories, conduction, convection, and radiation, all of which have their own equations that govern their procedures (Stefan-Boltzmann, Fourier, et al). Due to the evanescent effect found in optical research, it is speculated that at the nanoscale, heat transfer cannot be so sharply defined between the three categories as it is on the macroscopic scale. The focus of this project is to fabricate a chip that has a gap between two layers on the nanometer scale so that the transition between radiative heat transfer and conductive heat transfer can be studied.

This experiment never got through the fabrication step. There were various difficulties with the fabrication process that did not allow for the repeated production a successful chip. What will be outlined in this paper are the various attempts at making the nanogaps and the progress made in the fabrication of such devices.

Experimental Procedure:

The first method for making this gap was by spinning on e-beam PMMA-A4 resist onto a silicon-silicon dioxide wafer. Following this, micron sized holes were etched in the silicon dioxide so that a top layer of amorphous silicon (a-Si) could be deposited onto the wafer using plasma enhanced chemical vapor deposition (PECVD). Further, before attempting to remove the silicon dioxide release layer, a series of 4 μm wide trenches spaced 250 μm from each line, intersecting at 90 degree angles to each other were etched down to the substrate to allow the etchant to reach the release layer. Then various methods of undercutting were tested for the purpose of creating a gap between the two remaining layers of the chip. The results of the etches were then checked, first under a Nomarski interference microscope, and then a scanning electron microscope, if the situation warranted it.

The first attempts were used with a buffered oxide etch (BOE) of 20:1 and 6:1 ratios of hydrofluoric acid to ammonium fluoride, aqueous. This method of undercutting had the disadvantage of taking roughly 48 hours to complete, and lifted off much of the top layer of a-Si leaving the bare substrate of silicon. The areas that did not have complete liftoff had buckling in the gap area, leaving the sample useless for heat transfer experiments. The second etchant used was a 49% by volume hydrofluoric (HF) solution. This solution etched through the release layer in under 9 minutes, but repeated the same issues as that of the BOE, namely buckling and liftoff of the top layer.

The second round of fabrication tests took the previous etchants and added surfactant into the etching liquid. The idea behind using the surfactants was to increase the wetability of the hydrophobic silicon and reduce the surface tension of the liquid to help with the speed of the etching and to help with the problem of bubbling, as by reducing the surface tension, the size of the bubbles would decrease. For the HF dip, various concentrations of an industrial standard detergent, FL-70, were tested on the chips. For the BOE etch, a premixed superwet 6:1 formula was used. The results from this round of etchant tests gave limited success with one of the HF/detergent mixtures. One of the patterns of the nanogap survived the etching process intact. However, while attempting to cleave the sample to look at it under the SEM, edge on, the cleave destroyed the nanogap that was made. Further attempts using the same formula and method did not yield similar results, so the original success was determined to be a fluke. However, progress was still made during this round of tests. Some of the top a-Si layers remained, but a certain amount of buckling still took place. The next round of fabrication tests would prove helpful to this problem.

The third round of tests were inspired by looking back at the manual of the PECVD machine that warned of using etchants when the temperature of the deposition was low, saying that residual strains on the a-Si would cause it to buckle and collapse when using etchants. The limitations of the PECVD that we had at UNM dictated that instead of depositing at a higher temperature, an extra step of annealing would be necessary to rid the a-Si of the

residual strain. Two procedures were tested in this step. The first method was to use the outgassing station of a high vacuum chamber in a slowly controlled temperature rise to the annealing temperature of 650°C, and a direct insert into a 700°C furnace. The furnace samples came out of the furnace with an immediately noticeable change in the surface-the top layer powdered off of the chip. After etching with surfactant the chip proved to have almost no buckling, but none of the nanogaps survived the process with either test.

Future Work:

The next round of tests are scheduled to take place after the submission date of this paper, and will involve a complete shift from e-beam lithography to optical lithography. The optical lithography was earlier disregarded as an avenue of approach for the reason that the size of the posts were required to be larger than 1 μm, which was the largest size post that we were originally willing to entertain. It is hoped that further work with the optical lithography will help define the smallest reasonable gap size for successful creation of the nanogap as well as speeding up the process for creating samples to work with. With the original method of using e-beam resist, it takes roughly 24 man-hours to go from start to etching per sample, the optical lithography promises to take less than half the time to go from start to finish. In conclusion there is much more work that needs to be done with the fabrication of the nanogap before the heat transfer can be studied readily.

Acknowledgements:

Thank you to the National Science Foundation and the National Nanotechnology Infrastructure Network Research Experience for Undergraduates Program.