NDnano
Notre Dame Nanoscience and Technology

NDnano Summer Undergraduate Research
2022 Project Summary

1. Student name & home university:
AnnahMarie Behn, The University of Notre Dame

2. ND faculty name & department:
Dr. Gregory Snider, Dr. Alexei Orlov, Department of Electrical Engineering

3. Summer project title:
Adiabatic Capacitive Logic for Ultra Low-Power Electronics

4. Briefly describe new skills you acquired during your summer research:

In the Stinson Remick nanotechnology lab, I had the opportunity to learn several different software functionalities, including Origin, DAAS, PicoScope, LabWindows, and DesignSpark. From the various areas of the research process I was exposed to, I learned how to run measurements of capacitance on fabricated samples, how feedback loops and common mode rejection work, how to solder components smaller than 1206 onto a board, and the fundamentals of coding in C. Inside the nanofabrication facility, I received training on several machines, including the microscope, probe station, P6, PECVD, RIE, and stepper. Additionally, I learned how the research process can be tailored to the requirements of the project at hand and how group meetings with graduate students are facilitated.

5. Briefly share a practical application/end use of your research:

Instead of traditional CMOS circuits that generate energy waste through heat dissipation, adiabatic capacitive logic devices can be implemented in their place to reduce passive power loss.

6. 50- to 75-word abstract of your project:

Quasi-adiabatic reversible capacitive logic uses reversible logic and linear ramping to recycle energy. By utilizing this combination, pull-in and pull-out voltage change gradually instead of instantaneously, minimizing heat dissipation as the capacitor charges. From this concept, we researched the design and nanofabrication of Adiabatic Capacitive Logic devices designed with a voltage-controlled MEMs variable capacitor structure. These ACL devices are fundamentally free of passive power dissipation, so there is potential for more definitive output capacitance change in future iterations.

7. References for papers, posters, or presentations of your research:

[1] R. Celis-Cordova, A. O. Orlov, E. M. Williams, G. J. Quintero Cayaspo, J. J. Gose, A. F. Brown, J. D. Chisum, and G.L. Snider, "RF Reflectometry of NEMS Motional Capacitance with Micromanipulator Probe," 2022 IEEE Silicon Nanoelectronics Workshop (SNW), 2022,

One-page project summary that describes problem, project goal and your activities / results:

Quasi-adiabatic capacitive logic focuses on energy recycling in a system, and this conservation is accomplished through a combination of reversible logic and a variable capacitor network. In traditional CMOS circuits, when a voltage is applied to the input, the voltage across the entire circuit abruptly changes. This instantaneous change is what causes heat dissipation, or energy waste, in a system. In contrast, adiabatic logic employs a method called linear ramping. When a voltage is applied to the input through adiabatic logic, the voltage across the circuit changes smoothly. A tradeoff between energy and speed is then introduced, with less steep voltage ramping equating to lessened heat dissipation.

We researched the nanofabrication of ACL devices on this premise of energy recycling. An image of a fabricated device is shown below on the left side of Figure 1; a diagram of where input and output capacitance is observed is displayed on the right.

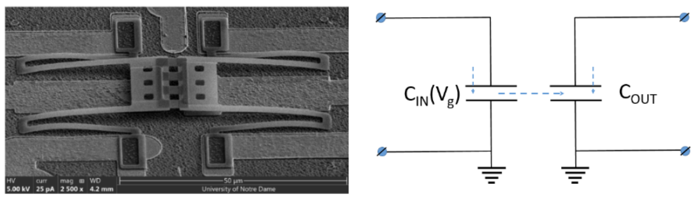

Figure 1. SEM captured image of fabricated ACL device and ACL device structure.

With a transimpedance amplifier connected to the "bottom" leg of the output capacitor in Fig 1b (which will be grounded in a functional device) and an applied AC signal to the other leg of the output capacitor, we measured the output capacitance of fabricated devices. The majority of devices failed to perform due to fabrication defects. One of the successful measurements is presented in Fig 2. In the measurement of current, we noted a smooth ramp in amperes which matched prior simulations. For the output capacitance, we observed a rapid change around -30 V, which indicates that the cantilever in the center of the device moved downward, made contact with the electrode, and changed the capacitance; however, when the bias changed to positive the output capacitance difference was no longer noted. Although the physical movement of the ACL device was still observed through a microscope, the electrical measurements do not consistently reflect this mechanic.

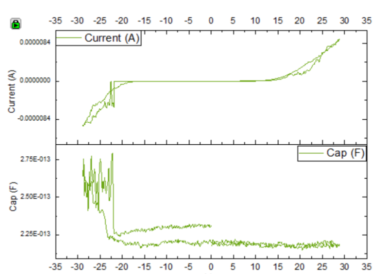

Figure 2. Output capacitance change measured in correlation with negative applied bias.

The reason for that is in the batch of devices that were tested, several parasitic capacitances were dominant. Our results show that the observed capacitive currents are strongly dependent on the photonic environment (i.e. if the device was exposed to light) and exhibit voltage dependence on the capacitance even in devices with broken cantilevers. Thanks to our discoveries, it was decided that the next generation of devices must utilize insulating (fused silica) rather than a silicon substrate. Additionally, the devices which are currently 75x50 microns in dimension may be fabricated at a larger size to create more stability for the cantilever of the device.