# Building and Testing Setups for Electrical Characterization of Silicon Nanomembranes

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## Introduction

Silicon Nanomembranes (SiNMs) offer new possibilities in flexible and high performance electronics. SiNMs are extremely thin (a few hundred nanometers to less than 10 nm) layers of single crystal silicon. The ratio of the thickness of the membranes to their lateral dimensions is on the order of $10^{-3}$ to $10^{-5}$, making SiNMs very flexible. SiNMs are layerable, transferable, bondable and can be patterned as electronic devices. Additionally, their electrical and mechanical properties can be modified through strain engineering.

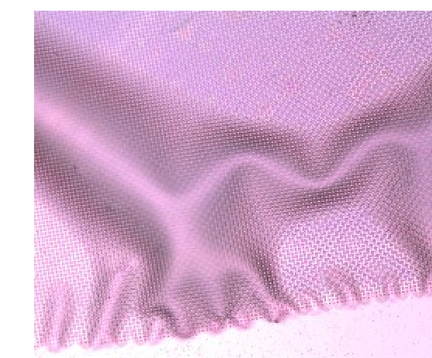

**Figure 1.** SiNMs are very flexible.

## Fabricating SiNMs

Thin layers are grown on top of a bulk substrate and then released by a selective etching process. Once released, membranes can be easily transferred to a new host.

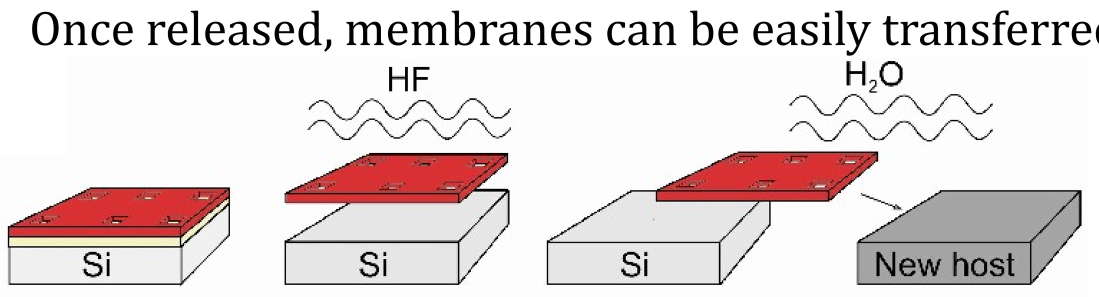


**Figure 2.** Membrane release and the wet transfer process.

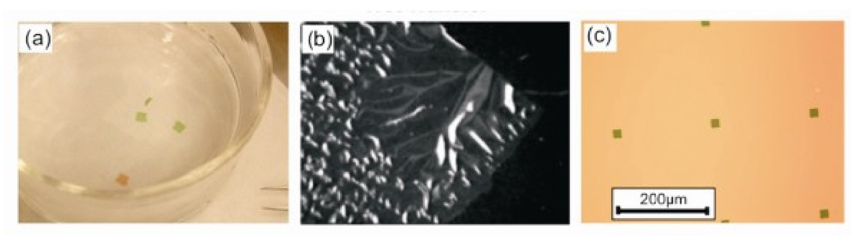


**Figure 3.** a) Membranes floating after release b)Membrane resting on new substrate while still wet c) Transferred membrane once dried and smoothed

## Electrical Transport

- In thin membranes, conductivity is very sensitive to surface and interface conditions. This is something that has not yet been extensively investigated.
- When SiNMs are strained, the band structure is altered causing changes in charge carrier mobility. In order to quantify these changes and further improve device performance, it is useful to measure the electrical properties of membranes.

## Van der Pauw Method

Sheet resistance is a measure used for thin membranes of a uniform thickness and is defined as resistivity divided by thickness, $R_S=\rho/t$. The Van der Pauw method provides a way to measure sheet resistance based upon a four point contact method.

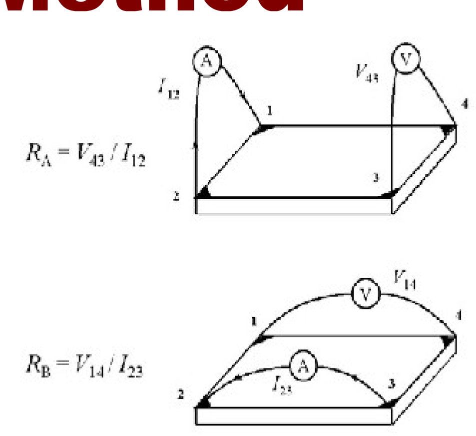


**Figure 4.** Configuation for Van der Pauw method.

**Steps for taking Van der Pauw measurents:**

- Apply a small current across one side of a sample while measuring voltage across the other side, and from this obtain a resistance by R=V/I.
- Take a series of reciprocal measurements to provide more accurate values.
- Reverse polarity and take all measurements again in the opposite direction which accounts for any offset voltages.
- Average the results to obtain two characteristic resistances, $R_{horizontal}$ and $R_{vertical}$.
- Calculate sheet resistance from $e^{-\pi R_{horizontal}/R_S} + e^{-\pi R_{vertical}/R_S} = 1$.

## Hall Method

The Hall effect causes a small potential difference, known as a Hall voltage, $V_H$, across a sample carrying a current in a uniform magnetic field.

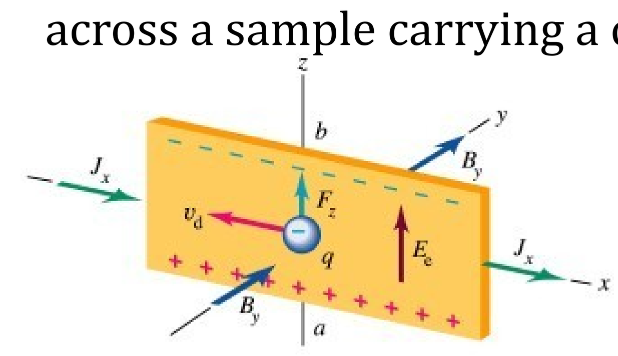

**Figure5.** Charge accumulation due to Hall effect.

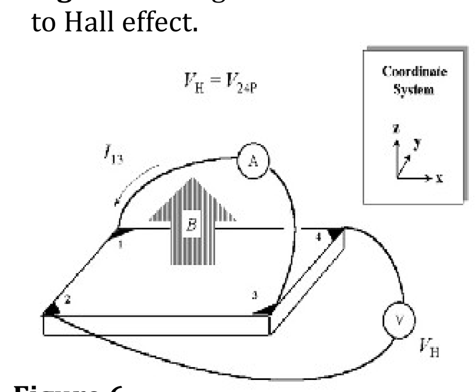

**Figure 6.** Configuration for Hall measurements.

**Steps for taking Hall measurements:**

- Apply uniform magnetic field, B.
- Apply a current across two opposite corners of a sample and measure the voltage across the other two corners.
- Take all of the reciprocal measurements and reverse the direction of the magnetic field and repeat the measurements.
- Find the difference between the corresponding voltage measurements from the positive and negative magnetic fields and then average these together for an overall Hall voltage.
- Calculate sheet carrier density by $n_S=IB/(q|V_H|)$.

## Device Under Test

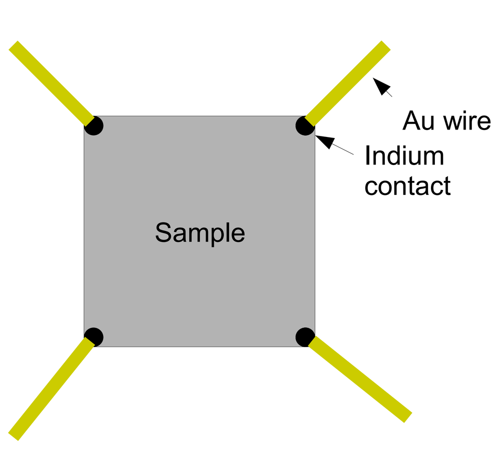


**Figure 6.** Contact arrangement for a device under test (DUT)

For theses measurements, I worked with samples 4 mm x 4 mm. I added indium contacts on each corner. Ideal contacts should be as small as possible and as close to the edges as possible. Once prepared, I connected the device under test (DUT) to a sample box. I held the DUT in place using a piece of double-stick tape. Additionally, a back gate can be added to the sample to obtain more information based on charge accumulation channels.

## Measurement Setups

For the **Van der Pauw measurements** setup, I made a box to hold the DUT and connect to a semiconductor parameter analyzer, which I used to apply a sweep of currents and measure voltages to obtain necessary resistance values.

**Figure 7.** DUT in sample box used for Van der Pauw measurements

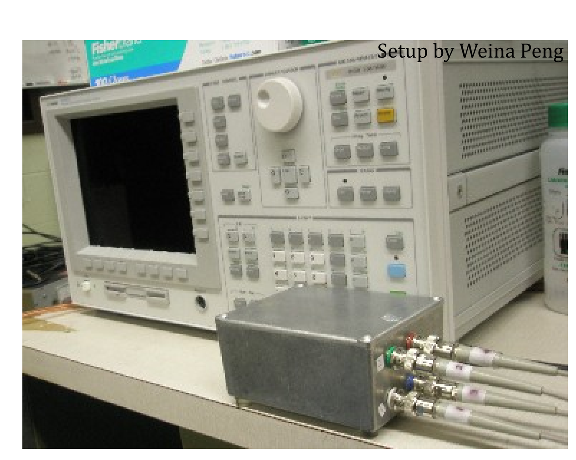


**Figure 8.** DUT connected to semiconductor parameter analyzer for Van der Pauw measurements

For the **Hall measurements** setup, I used a smaller, nonmagnetic sample box with a support to hold it in place between the poles of a large electromagnet. I used a magnet with an adjustable field between 0 T and 2 T.

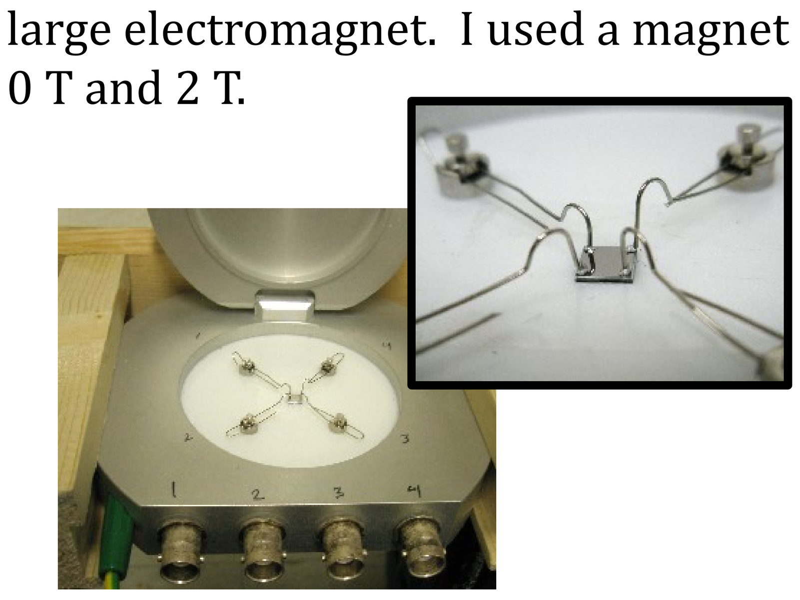

**Figure 9.** DUT prepared for Hall measurements with closeup of sample

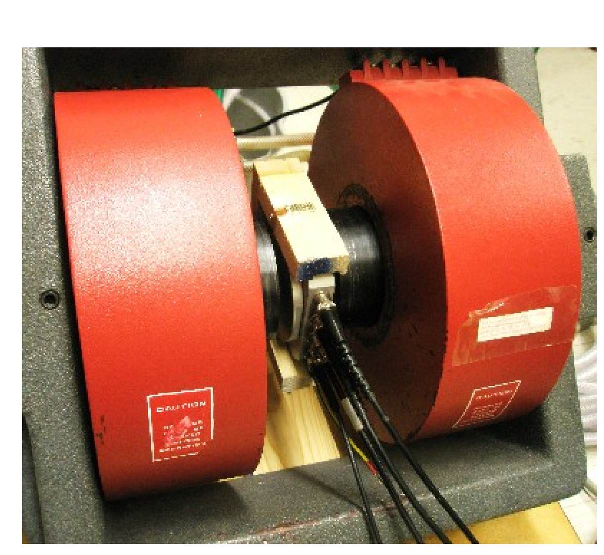

**Figure 10.** DUT positioned in magnet for Hall measurements

## Next Steps

- All of these measurements can be automated and streamlined by the use of LabView programming. This would make it much easier and efficient to collect greater volumes of data and therefore improve accuracy of measurements.
- All of these setups can be used to measure many types of SiNMs, with many different configurations of strain or other conditions.

## Acknowledgments

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## References

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