evelopment of a 3_ω Thermal Conductivity Measurement System for Thin Dielectric Films with Experimental Validation

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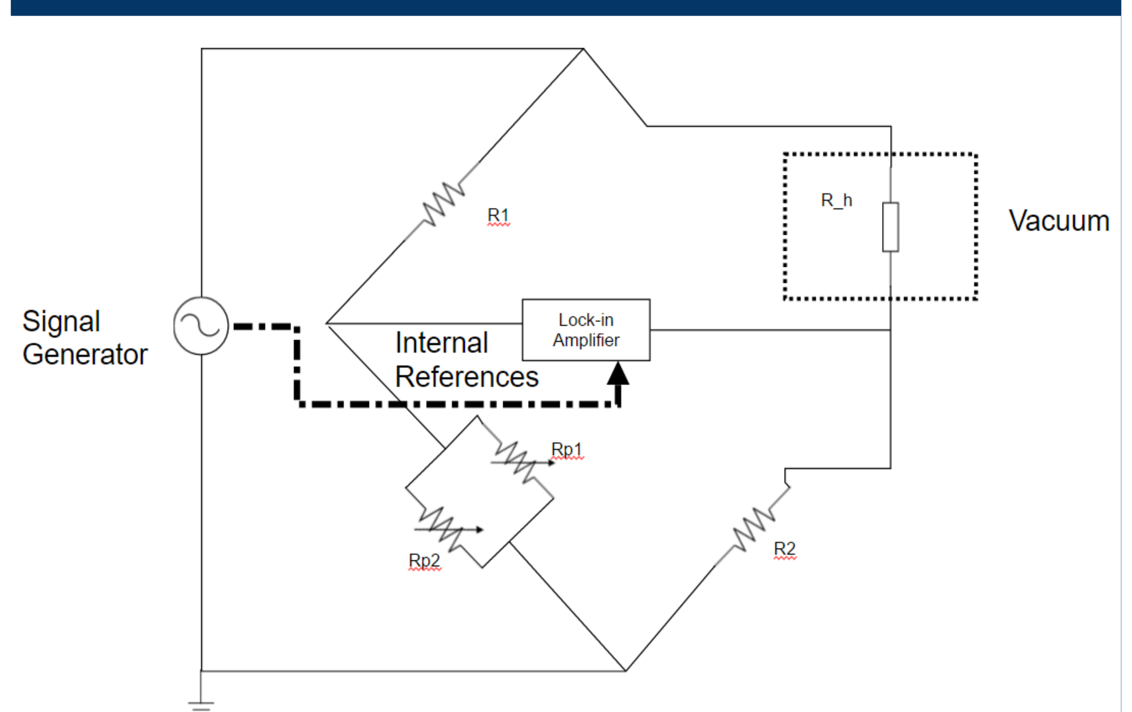
I. Introduction

A thin film is a fabricated microstructure in which the thickness of the film is much smaller than the lateral dimensions. The increase of technology of many components and devices used in state-of-the-art engineering system, especially devices with integrated circuit such as transistors, memory and all kinds of semiconductors, relies heavily on thin film technology. Thermal properties of thin films, especially thermal conductivity, have played important roles on the performance, functionality, and the reliability of micro-fabricated device. Popular methods for measuring film material included time-domain thermoreflectance method (TDTR), frequency-domain thermoreflectance (FDTR) and 3ω method. Results has agreed with previous measurement, and has shown 3ω method can provide high accuracy of thermal properties within wide temperature range with low cost. Future work including study the anisotropy of film material using 3ω method is under developing.

Figure 1 - 3 measurement circuit diagram



II. Method

3ω method was developed by D.Cahill in the early 1990s:

- When applying an alternating current frequency of ω through a heater, it creates a small voltage signal across the heater with frequency of 3ω. This signal contains thermal properties of the samples, which can be extracted using Lock-in Amplifier;
- With several assumptions, the cross-plane thermal conductivity of the film k can be determined from:

$$k=\frac{V^3 \ln(\omega_2/\omega_1)}{4\pi l R^2 (V_{3,1}-V_{3,2})}\frac{dR}{dT}$$

- The heater can be used as a temperature probe. The temperature oscillation of the heater ΔT is:

$$\Delta T=4\frac{dR}{dT}\frac{R}{V}V_3$$

- All of those properties above are measurable;
- The schematic diagram of circuit for measuring thermal properties is displayed in Figure 1.

III. Sample Fabrication

- Well-known film material can be used to validate accuracy of the system.
  - Chosen 300 nm pre-grown Silicon Nitride(Si_3N_4) film;
  - Used Gold as heater due to its large temperature coefficients of resistances.
  - Performed photolithography on pre-grown film, and use Physical Vapor Deposition (PVD) to deposit gold pattern for Four Point Probe measurement.
    - Figure 2 displays the Scanning Electron Microscope (SEM) image

Figure 2 – SEM image of metal pattern

Figure 4 – Future Development

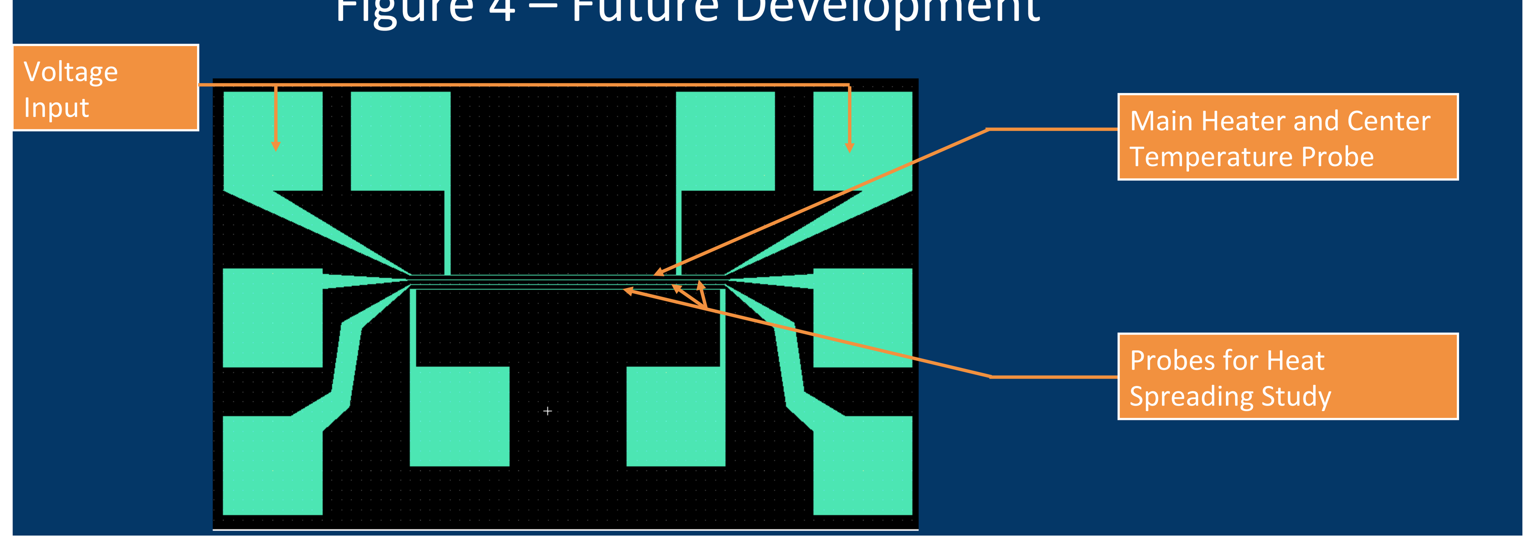
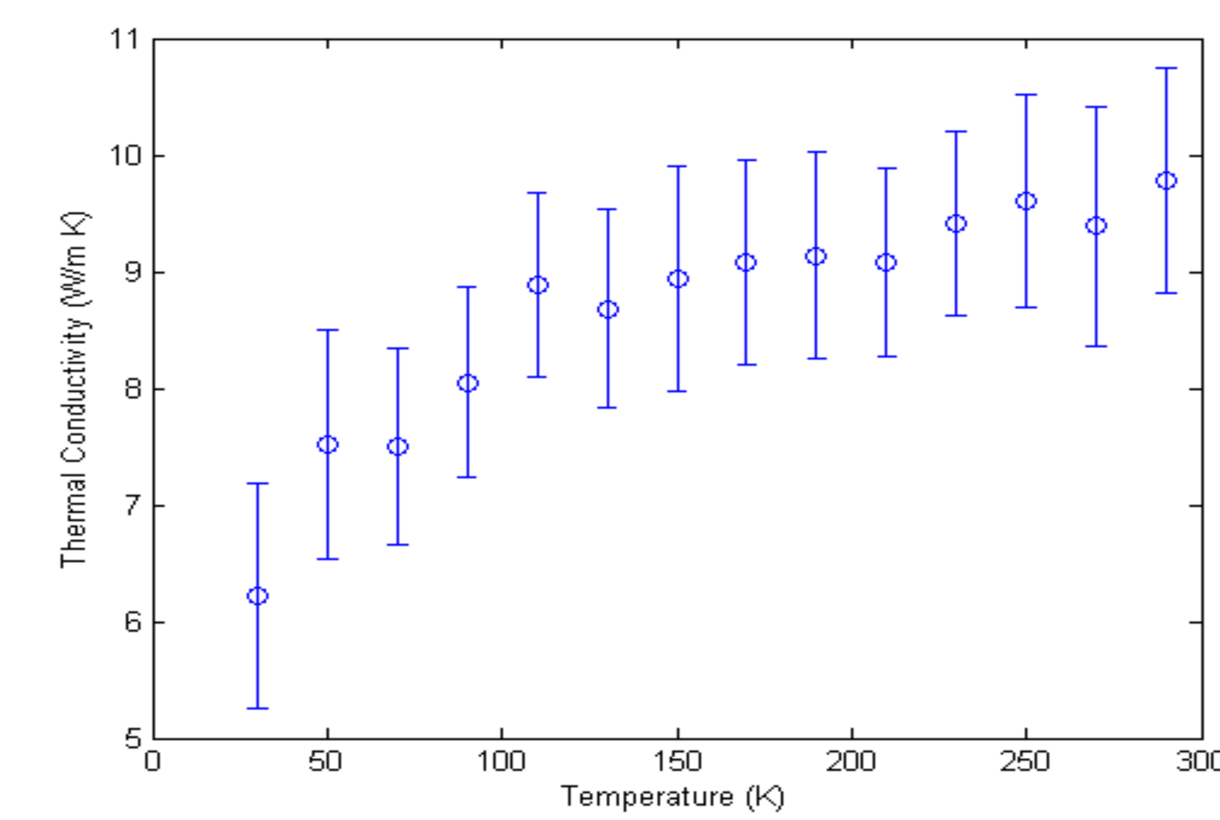


Figure 3 – Thermal conductivity from 30 K- 290 K



IV. Results and Conclusion

- The results of thermal conductivity from 30K-270K of Si_3N_4 is displayed in Figure 3;
- *k* increases as temperature increase, which agrees with Wiedemann Franz Law;
- The result matches with published results (reference 3);
- The radiation effect will become significant near lower temperature region. Hence a radiation shield covering the sample is recommended.

V. Future Work

- With higher voltage crossing the heater, the temperature wave will be stronger and therefore spread further. By placing more probes 100 μm away from the center heater, the probes will be able to capture the temperature changes, and therefore have a heat distribution understanding on the film. Furthermore, we can deduct the anisotropy thermal conductivity. Figure 4 displays the metal pattern schematic for study the anisotropy for film material.

VI. References

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