SThM characterisation of local thermal properties of semiconductors and insulators on the nanometer scale

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INTRODUCTION

Semiconductor technology evolution is leading to a reduction of the size of the electronic components from the micro- to the nanoscale. One of the main challenges in this field is understanding the thermal behaviour of these nanostructures. Here we show that the thermal conductivity of nanoscale volumes of silicon samples with various doping and thermal properties of sub—micrometre SiOx layers can be reliably characterised via scanning thermal microscopy (SThM).

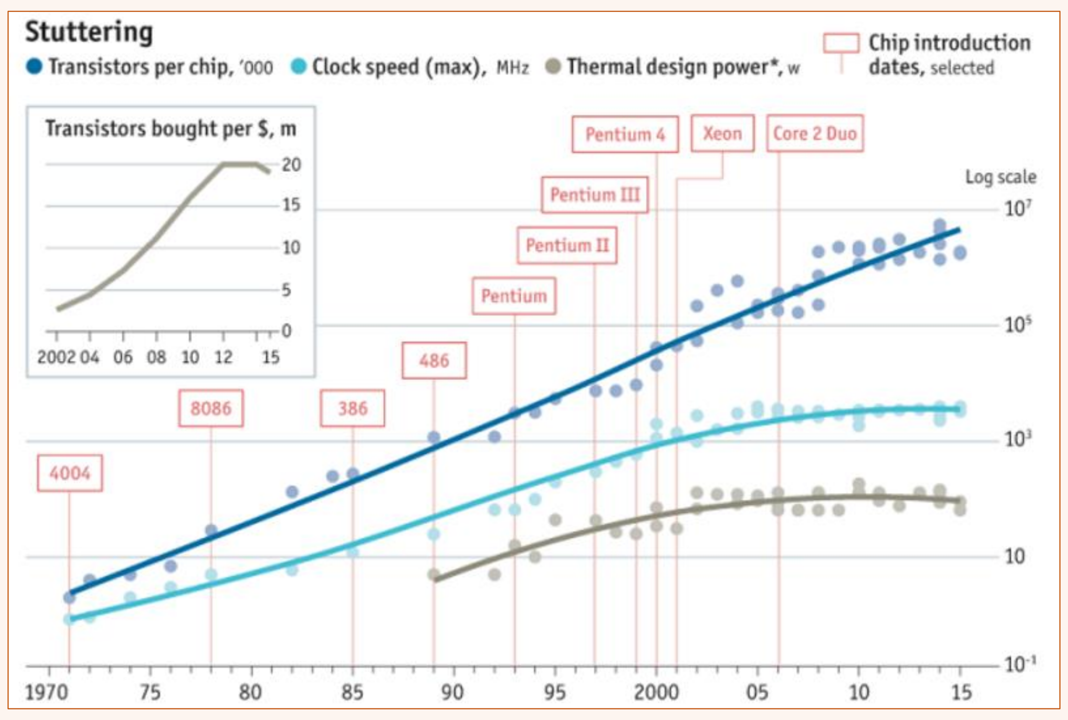
MOTIVATION

ENSURING THE CONTINUITY OF MOORE'S LAW

- High speed electronics
- Spatial shrinking nanometer scale

CHALLENGE

THERMAL MANAGEMENT AND POWER DISSIPATION



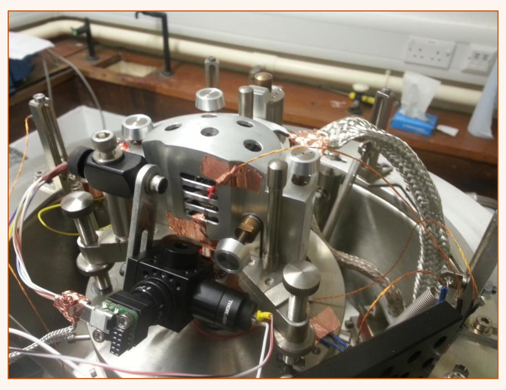
Moore's law. Image source: Intel

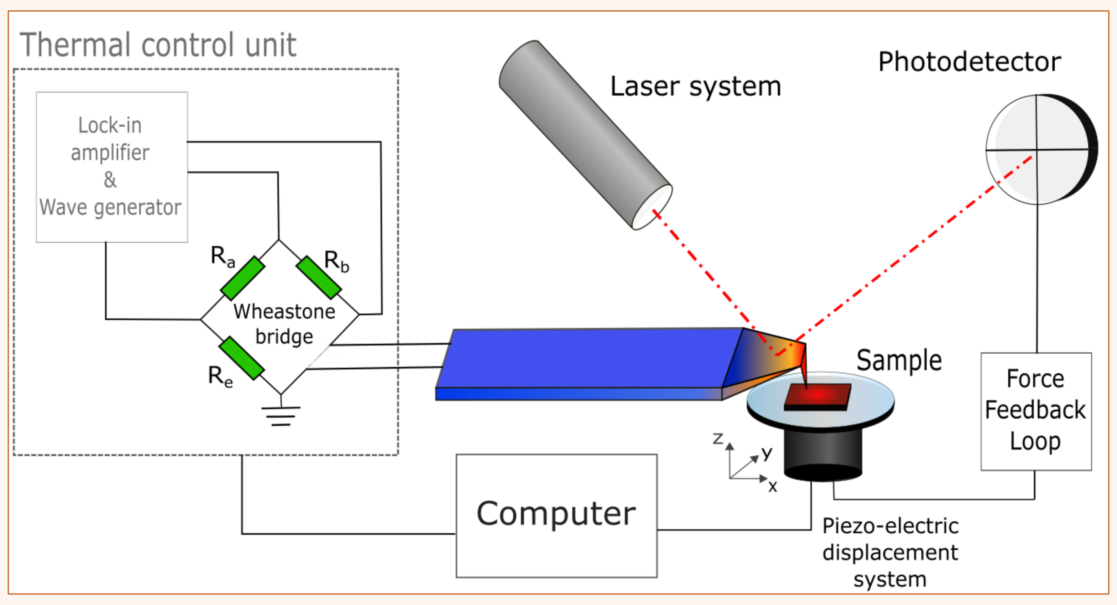
SYSTEM

SCANNING THERMAL MICROSCOPY (SThM)

MULTIFUNCTIONAL SPM: Modified NT-MDT Solver

- ❑ High resolution AFM topography
- ❑ Heat transport maps



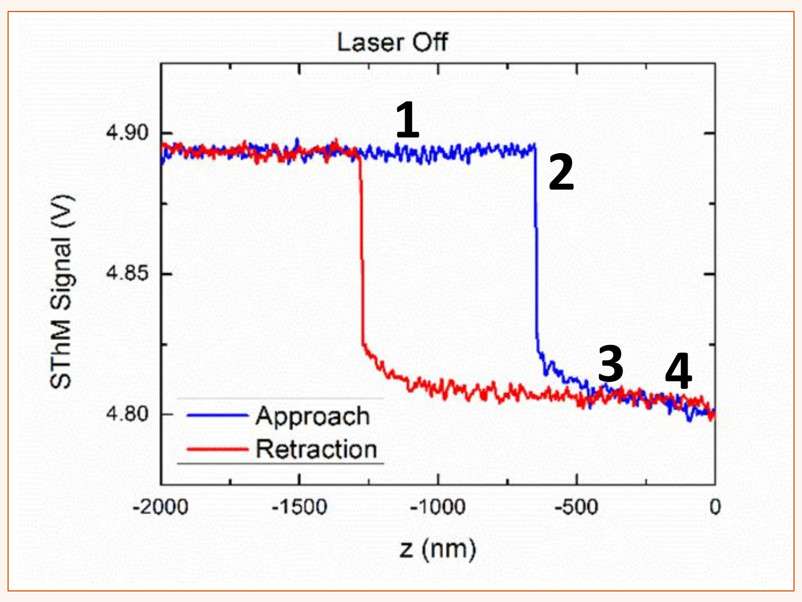


- Pressure conditions:
  - Ambient: $10^2\,torr$
  - Vacuum: $10^{-7}\,torr$
- Probe:
  - Si_3N_4 with a Pd coating
  - Doped Si

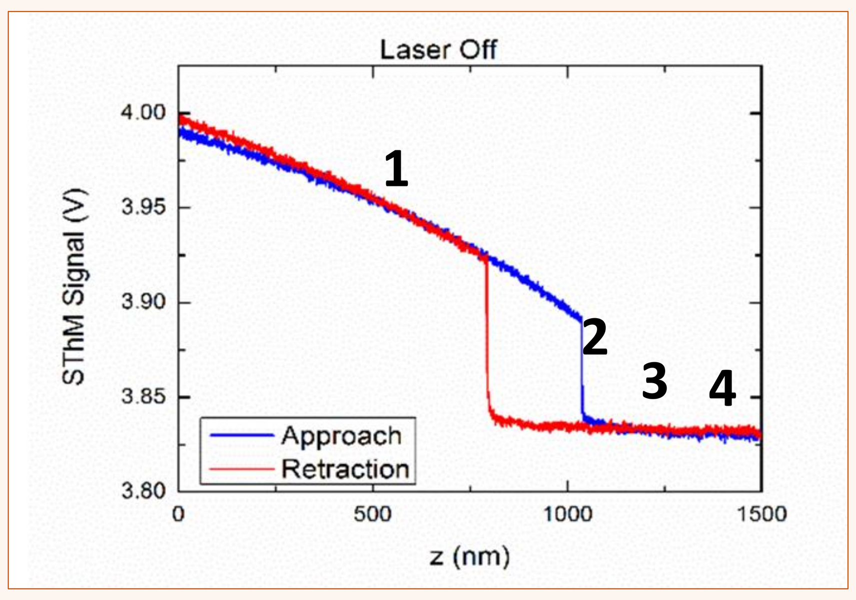
METHODOLOGY

FS-SThM: Sample – probe approach-retraction curves of SThM thermal signal d*V*/*V* response. Increase of thermal conductivity increases d*V*/*V*

VACUUM



AMBIENT

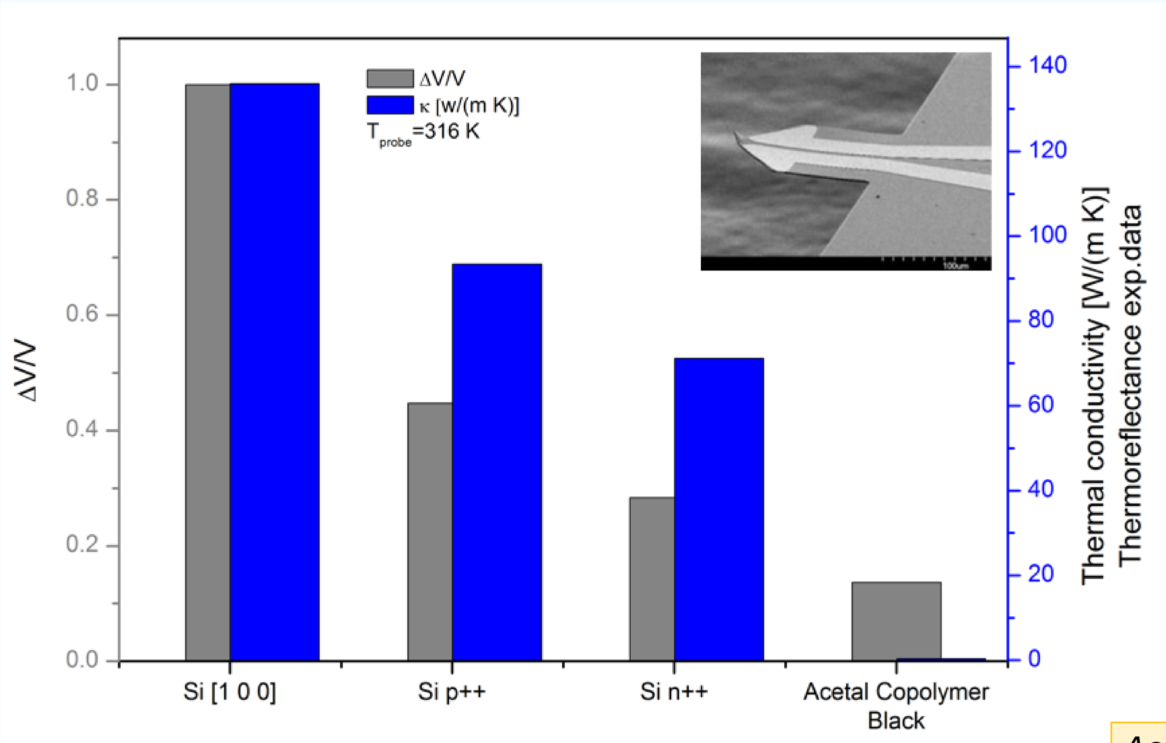


1.-**Approach** 2.-**Contact** 3.-**Stabilization** 4.-**Measurement**

RESULTS

THERMAL CHARACTERIZATION OF DIFFERENTLY DOPED SILICON SAMPLES VS A REFERENCE POLYMER SAMPLE

- Probe: Commmercial Si_3N_4 with a Pd thin film resistive temperature sensor (Kelvin Nanotechnology, KNT). Tip radius <100 nm.
- Measurement conditions: 10^2 torr, $\sim 298\,K$
- Probed volume (~ 50x50x50 nm³) is linked with the dimensions of the contact



$$\frac{\Delta V}{V} = \frac{V_{NC} - V_C}{V_{NC}}$$

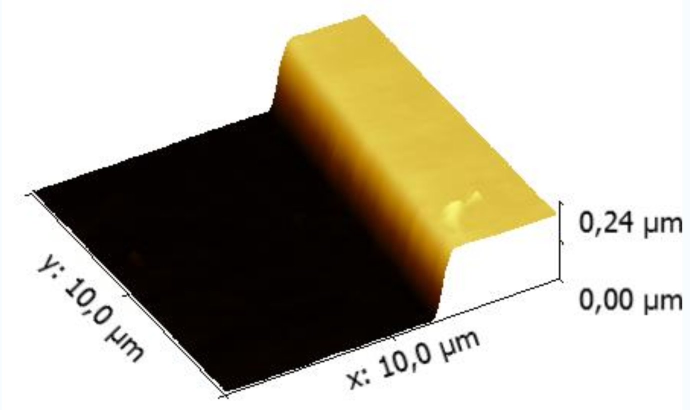
$$\frac{\Delta V}{V} = \sim \kappa\, [W/(m \cdot K)]$$

Top-right figure: SEM image of the Si_3N_4 probe. Image source: Kelvin Nanotechnology

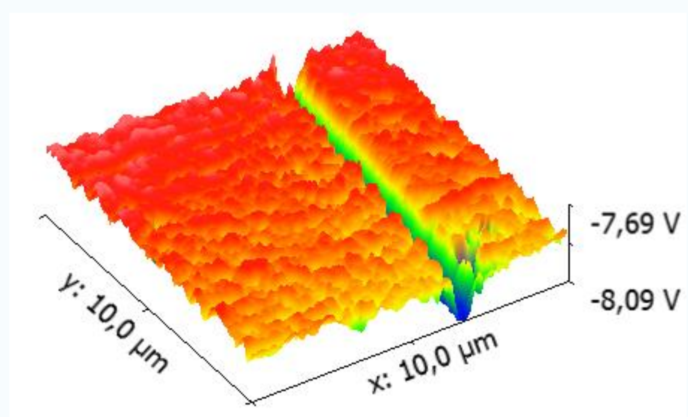
Acknowledgment: Thermoreflectance data was taken by Gill Tessier and Abeer Al Mohtar at Their University, Paris

THERMAL CHARACTERIZATION OF SiO_2 STEPS

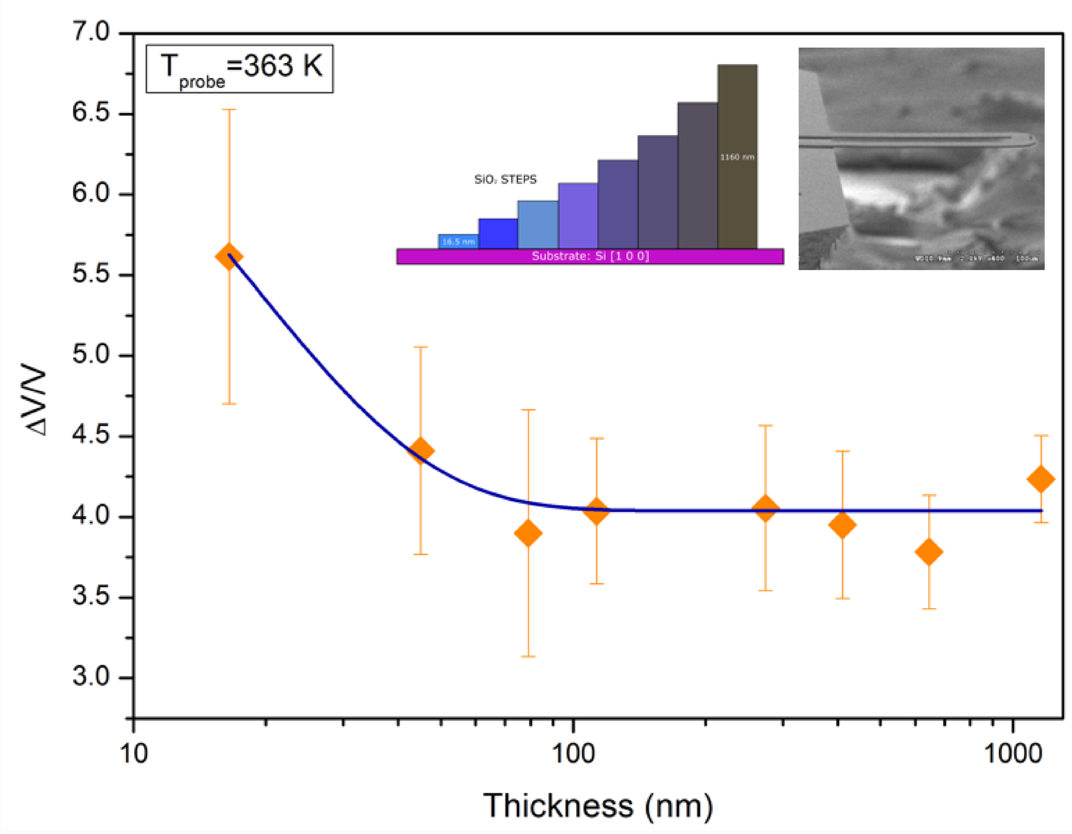
- Sample: SiO_2 steps of increasing thickness, ranging from 10 nm to 1200 nm over a substrate of single crystal Si.
- Probe: Doped silicon (Anasys instruments). Tip radius <30 nm.
- Measurement conditions: 10^{-7} torr, ~ 298
- Thermal conductance behaviour: Decreasing tendency from 0-100 nm, probably due to the influence of the underlying Si, and saturation for the layers of thickness > 100 nm.



Step topography



Step thermal response



Top-right figure: DSi probe. Image source: Anasys instruments

CONCLUSIONS & FUTURE WORK

- SThM allowed to reliably differentiate the thermal conductivity of Si samples with different doping concentration, as well as the thermal conductance of SiO_2 layers of increasing thickness (ranging between 10-100nm). The probed volume in both cases was below 50x50x50 nm³ with the spatial resolution exceeding 50 nm.
- Using high vacuum conditions and no laser during the measurements allowed to significantly increase measurement precision.
- NEXT STEP: Thermal characterization on the nanoscale of 2D material based heterostructures by using High Vacuum SThM

REFERENCES

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[2] Tovee, P., Pumarol, M., Zeze, D., Kjoller, K. & Kolosov, O. Nanoscale spatial resolution probes for scanning thermal microscopy of solid state materials. *Journal of Applied Physics* **112**, 114317, doi:10.1063/1.4767923 (2012).