The interconnect bottleneck

Further improvement of chips is limited by electromigration (EM) and RC-delay. These effects are temperature dependent and a new measurement technique is needed to investigate temperature distribution [1]. Scanning thermal microscopy (SThM) is a modified atomic force microscopy (AFM) method capable of 2D temperature mapping on nanoscale. Carbon nanotubes (CNT) could replace copper as interconnects, due to their extraordinary thermal and electrical properties.

Scanning thermal microscopy

For this SThM a resistive heater is used as thermal probe. A temperature change in the tip changes the resistance of the heater, which is measured. Quantitative results are possible, because of a calibration of the heater [2]. The lateral resolution is below 20 nm, the thermal resolution is 30 mK [3].

Carbon Nanotubes

The investigated sample is a supported individual multi walled carbon nanotube (MWCNT) on silicon oxide, contacted with 35 nm thick contacts. The center of the MWCNT is damaged by a focused ion beam to form a local resistance. The sample is obtained by Koji Ishibashi and coworkers (RIKEN, Japan). By SThM the topography and the thermal field are measured. The barrier is seen in the thermal signal, but not in the topography. A thermal signal is also obtained through the contacts.

Results

Kelvin probe force microscopy was performed by Tino Wagner and Andreas Stemmer (Nanotechnology group, ETH) to obtain the resistivity of the Carbon Nanotube.

Analytical solutions of the 1D heat equation are fitted to the obtained results at different temperatures.

\[
\frac{\partial T}{\partial t} + \nabla \cdot (k \nabla T) = \dot{q}
\]  

Thermal conductivity

The obtained conductivity shows a rising trend with temperature. The quadratic solution that neglects the conductance into the substrate and the hyperbolic solution that accounts for it give nearly the same results.

Conductance into the substrate

The conductance into the substrate is negligibly small. The substrate still has a huge influence as it blocks phonon modes that are the main heat carriers of MWCNTs. The conductivities are an order of magnitude smaller than the ones of suspended MWCNTs [4].

Conclusions

Thermal properties of supported single MWCNTs were investigated. SThM was proven successful as it obtained coherent data with literature. The thermal conductivity was determined to be 350 W m⁻¹K⁻¹ at 80 °C up to 860 W m⁻¹K⁻¹ at 420 °C. Future experiments could investigate thermal contact coupling as a thermal signal is obtained through the contacting Palladium.

References:

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Supervised by:
Guillermo Villanueva (EPFL)
Bernd Gotsmann (IBM)
Fabian Könemann (IBM)