ELECTROTHERMAL MODELING OF CU-CNT COMPOSITE TSVS AND GNR INTERCONNECTS FOR 3D IC

KOMAL SABLE BHAWANA KISHORE

INDIAN INSTITUTE OF TECHNOLOGY, DHANBAD

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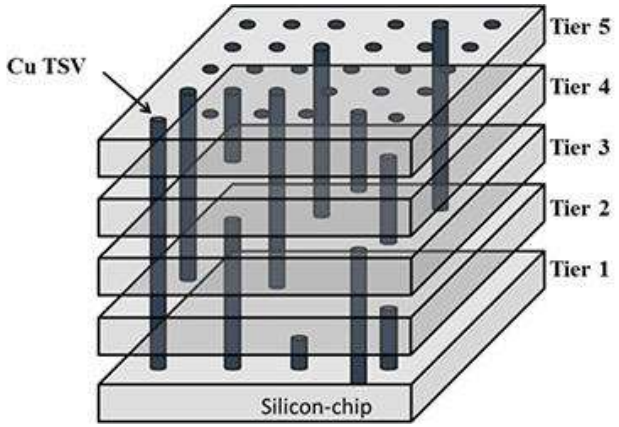
OVERVIEW

- Need for 3D ICs
- Problems with traditional Copper material
- Motivation for using Carbon-based Material
- TSV-Interconnect Structure
- Mathematical Implementation
- Comsol Simulation
- Electrical Effect
- Thermal Effect
- Conclusion

NEED FOR 3D IC

- **3D IC is a promising technology that can help us to achieve high integration density and enhance the system performance.**
- **The wire length becomes shorter in case of 3D IC structure and helps to reduce interconnect power, interconnect delay and helps to improve routing congestion.**
- **They not only help in signal transmission but also allow the heat to be distributed among the layers to avoid formation of hot spots[1]**



PROBLEMS WITH TRADITIONAL COPPER MATERIAL

- **Due to degrading conductivity of copper at nanoscale regime due to electromigration, surface roughness scattering and grain boundary scattering, it does not perform well[2].**
- **Another important issue is that the resistance of the interconnects represents a parasitic contribution to the signal delay in integrated circuits.**
- **The thermal conductivity of copper is less that causes hot spot generation in 3D ICs[2].**

Therefore copper needs a replacement.

MOTIVATION FOR USING CARBON-BASED MATERIAL

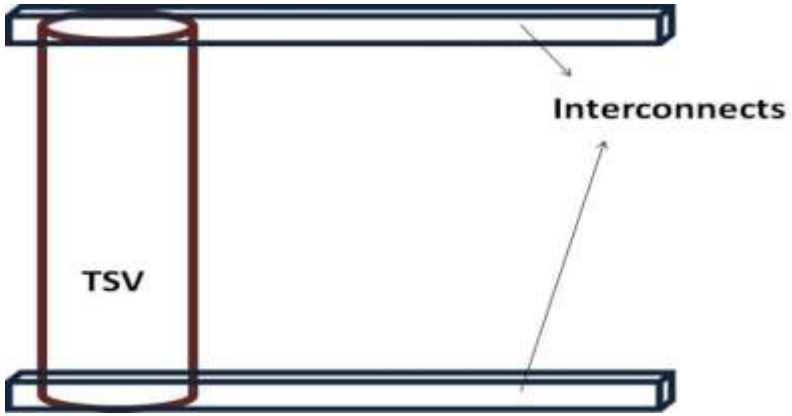
- **Carbon nanotubes (CNTs) and graphene nanoribbons (GNRs), whose promising electrical, thermal, and mechanical properties make them attractive candidates for next-generation integrated circuit (IC) applications.**
- **Nanostructures, such as CNTs and GNRs, have unique properties that include low-dimensional conduction and longer mean free path.**
- **The measured high thermal conductivity of CNTs and GNRs is higher than that of diamond.**
- **Horizontal GNRs are more controllable in fabrication point of view having higher in-plane thermal conductivity and vertical CNTs having higher conductivity in the vertical direction.**

TSV-INTERCONNECT STRUCTURE

Boris Vaisband in his work[3], has carried out electrothermal modeling of CNT TSV and GNR interconnects. He has also derived the electrical and thermal resistance of the interface between the TSV and interconnect structure.

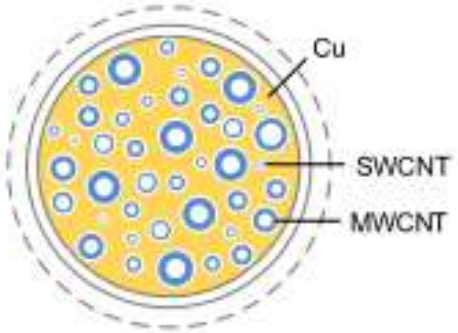
We take a simple TSV and interconnect structure to study the electrothermal properties.

Multi-layered GNR are used as interconnects and Cu-CNT composite is used as TSV.



MATHEMATICAL IMPLEMENTATION

In this work, we try to model the electrical and thermal properties of the interface between the Cu-CNT composite and GNR interconnect.



To calculate the overall thermal and electrical conductivity of the Cu-CNT composite we refer [4],

$$\sigma_{eff} = (1 - f_{CNT})\sigma_{Cu} + f_{CNT}.\sigma_{CNT}$$

where, $f_{CNT} = N_{CNT}.f_m$

N_{CNT} **= Number of CNTs and** f_m **= Fraction of metallic CNTs**

THERMAL MODELING

CNT-GNR Interface

A study of thermal transport across CNT-GNR structure is carried out by Jungkyu Park in [5], a reverse nonequilibrium molecular dynamics (RNEMD) is utilized to calculate thermal conductivity in the SWCNT-graphene super structures by imposing a heat flux and measuring the induced temperature gradient,

$$k = \frac{\langle q \rangle}{\left\langle \frac{dT}{dx} \right\rangle}$$

Cu-GNR Interface

During the interfacial thermal transport process, the energy decay of GNR is only caused by its thermal energy loss at the interface. Therefore, given the energy and temperature evolutions of the GNR system, the interfacial thermal resistance (R) between GNR–Cu can be calculated using the equation[6],

$$\frac{\partial E_t}{\partial t} = A(T_{GNR} - T_{Cu})\ R$$

ELECTRICAL MODELING

CNT-GNR Interface

Due to similar bonding at the interface between the CNT-GNR interface, the properties at the interface are similar to the properties at the grain boundaries.

When a device dimension crosses a grain boundary its resistance increases from[7],

$$R = \rho_{\square} \left(\frac{L}{W}\right) \text{ to } R` = \rho_{\square} \left(\frac{L}{W}\right) + \left(\frac{\rho_{GB}}{W}\right)$$

Cu-GNR Interface

As discussed in [8], first principle of Quantum Mechanics was used to obtain interface resistance.

The total resistance offered is given by,

$$R_T = R_{cont} + R_{CNT} + \text{scattering}$$

Scattering is ignored because the distance is much smaller than the mean-free path of electron.

COMSOL SIMULATION

The study of the proposed structure can be classified into

- **Thermal Analysis**
- **Electrical Analysis**

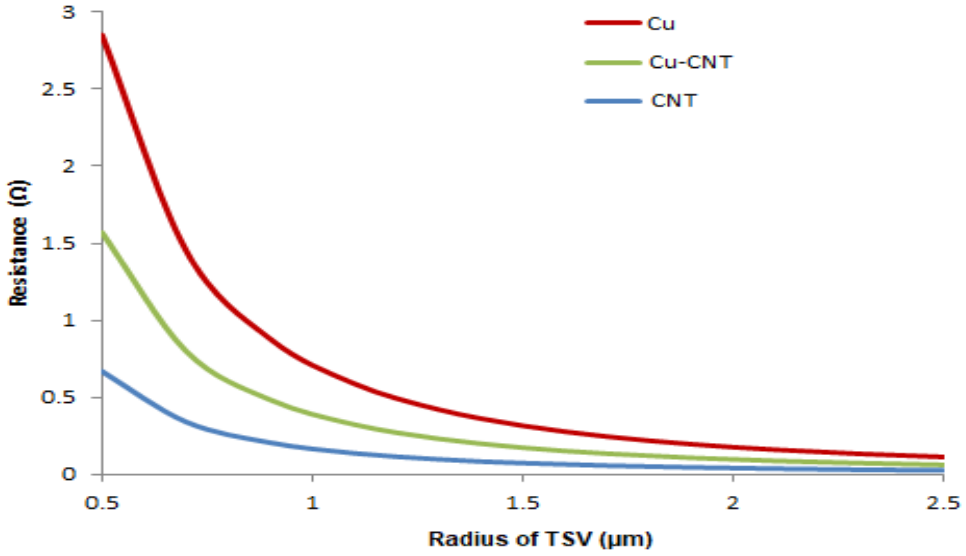
Three different materials; copper, CNT and Cu-CNT composite are used as TSV material and a comparative study is carried out.

Interconnect used is GNR for all the three cases.

ELECTRICAL ANALYSIS

Also copper offers the highest resistance and the resistance offered by CNT is the lowest.

The composite offers an intermediate resistance of the three materials.



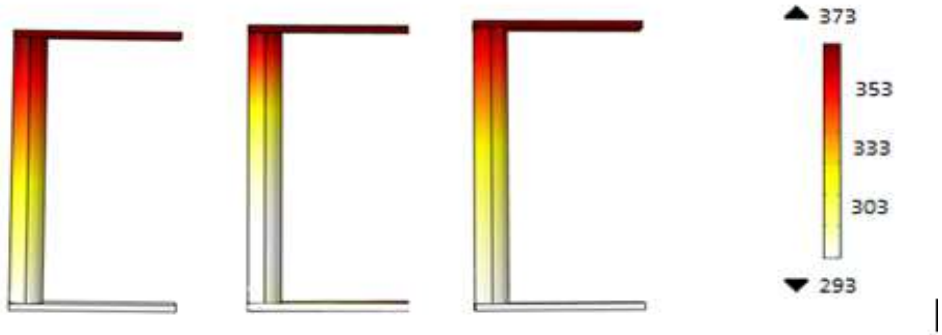
THERMAL ANALYSIS

The temperature plot of TSV and interconnect structure for

a. Copper TSV

b. CNT TSV

c. Cu-CNT TSV

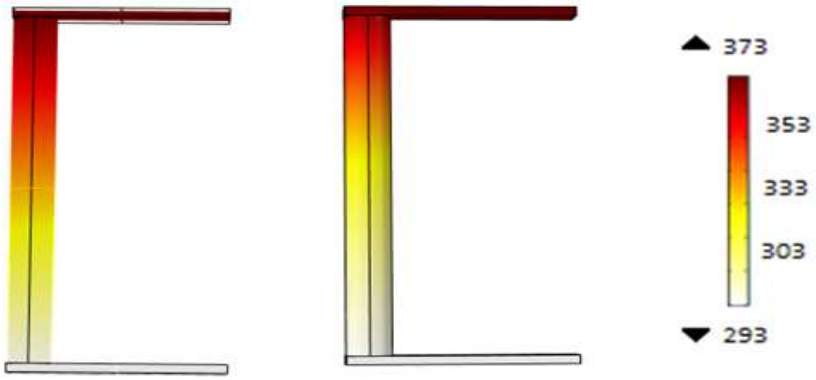


(a) (b) (c)

TEMPERATURE PROFILE FOR DIFFERENT FRACTIONS OF CNT IN THE COMPOSITE

Depending on the fabrication process the propotion of CNT in the composite may vary.

Here two cases (a) 0.3 fraction and (b) 0.7 fraction of CNT in the composite are considered and compared.



(a) **(b)**

CONCLUSION

Thus it was possible to carry out electrical and thermal analysis of TSV and interconnect structure using COMSOL Multiphysics. It can be seen that carbon-based material can perform better if used for fabricating 3D IC structure. Also similar bonding structure obtained at CNT-GNR interface can help to reduce the interface thermal and electrical resistance.

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THANK YOU….