HAL
open science

A Look Into Physical Modeling and Design for Carbon Nanotube based Circuits

Aida Todri-Sanial

To cite this version:

Aida Todri-Sanial. A Look Into Physical Modeling and Design for Carbon Nanotube based Circuits. CASS 2020 - 10th IEEE CASS Rio Grande do Sul Workshop, Nov 2020, Virtual, Brazil. lirmm-03025221

HAL Id: lirmm-03025221

https://hal-lirmm.ccsd.cnrs.fr/lirmm-03025221

Submitted on 26 Nov 2020

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Title: **A Look Into Physical Modeling and Design for Carbon Nanotube based Circuits**

Speaker: Aida Todri-Sanial
Director of Research, CNRS
Microelectronics Department
LIRMM, University of Montpellier, France

Abstract: This talk aims to give an in-depth look into using carbon nanotubes as back-end-of-line interconnects from process, modeling to physical design. The talk is organized into two parts. The first part provides an in-depth overview of the process and growth of carbon nanotubes and their resistance measurements. In the second part, the talk is dedicated to investigating carbon nanotubes for digital logic cells such as interconnects for signal, power and ground interconnect material. Due to the low-temperature growth, carbon nanotubes inherit a lot of defects that worsen its electrical resistance and ballistics transport. We investigate the doping of CNTs and show both experimental and simulations results of doped CNTs and their improved resistance. We compare the performance, power and area metrics of digital logics cells with conventional copper and carbon nanotube interconnects (undoped and doped) to highlight the advantages and limitations of carbon nanotube BEOL interconnects. Extended references highlighted in this work are listed below.

Video: https://www.youtube.com/watch?v=vZ6fwlMhUAg

References:

1. A. Todri-Sanial, J. Dijon and A. Maffuci, "Carbon nanotubes for Interconnects: Process, Design and Applications," book by Springer 2017, ISBN: 978-3-319-29746-0.
2. A. Todri-Sanial, "Exploring Carbon Nanotubes for 3D Power Delivery," book chapter in *Carbon nanotube Interconnect: Process, Design, and Applications*, Edited by A. Todri-Sanial, J. Dijon, and A. Maffucci, Springer 2017, ISBN: 978-3-319-29746-0.
3. J. Liang, R. Chen, R. Ramos, J. Lee, H. Okuno, D. Kalita, V. Georgiev, S. Berrada, T. Sadi, B. Uhlig, K. Lilienthal A. Dhavamani, F. Konemann, B. Gotsmann, G. Goncalves, B. Chen, A. Asenov, J. Dijon, A. Todri-Sanial, "Investigation of Pt-Salt Doped Stand-Alone Multi-Wall Carbon Nanotubes for On-Chip Interconnect Applications," in *IEEE Transactions on Electron Devices*. doi: 10.1109/TED.2019.2901658.
4. R. Chen J. Liang, J. Lee, V. P. Georgiev, R. Ramos, H. Okuno, D. Kalita, Y. Cheng, L. Zhang, R. R. Pandey, S. Amoroso, C. Millar A. Asenov, J, Dijon, A. Todri-Sanial, "Variability Study of MWCNT Local Interconnects Considering Defects and Contact Resistances - Part I: Pristine MWCNT", in *IEEE Transactions on Electron Devices*, 2018, doi: 10.1109/TED.2018.2868421.
5. R. Chen J. Liang, J. Lee, V. P. Georgiev, R. Ramos, H. Okuno, D. Kalita, Y. Cheng, L. Zhang, R. R. Pandey, S. Amoroso, C. Millar A. Asenov, J. Dijon, A. Todri-Sanial, "Variability Study of MWCNT Local Interconnects Considering Defects and Contact Resistances - Part II: Impact of Charge Transfer Doping", in *IEEE Transactions on Electron Devices*, 2018, doi: 10.1109/TED.2018.2868424.
6. J. Lee, S. Berrada, F. Adamu-Lema, H. Carrillo-Nunez, N. Nagy, V. Georgiev, T. Sadi, J. Liang, R. Ramos, D. Kalita, K. Lilienthal, M. Wislicenus, R. Pandey, B. Chen, K, Teo, G. Goncalves, H. Okuno, B. Uhlig, A. Todri-Sanial, J. Dijon, A. Asenov, "Understanding Electromigration in Cu-CNT Composite Interconnects: A Multiscale Electro-Thermal Simulation Study," in *IEEE Transactions on Electron Devices*, vol. 65, no. 9, pp. 3884-3892, September 2018, doi: 10.1109/TED.2018.2853550.
7. J. Liang, J. Lee, S. Berrada, V. Georgiev, R. R. Pandey, R. Chen, A. Asenov, A. Todri-Sanial, "Atomistic to Circuit-Level Modeling of Doped SWCNT for On-Chip Interconnects," in *IEEE Transactions on Nanotechnology*, doi: 10.1109/TNANO.2018.2802320.
8. A. Todri-Sanial, R. Ramos, H. Okuno, J. Dijon, A. Dhavamani, M. Widlicenus, K. Lilienthal, B. Uhlig, T. Sadi, V. Georgiev, A. Asenov, S. Amoroso, A. Pender, A. Brown, C. Millar, F. Motzfeld, B. Gotsmann, J. Liang, G. Goncalves, N. Rupesinghe, K. Teo, "A Survey of Carbon Nanotube Interconnects for Energy Efficient Integrated Circuits," in *IEEE Circuits and Systems Magazine*, vol. 17, no. 2, pp. 47-62, Secondquarter 2017. doi: 10.1109/MCAS.2017.2689538.
9. A. Magnani, M. de Magistris, A. Todri-Sanial and A. Maffucci, "Electrothermal Analysis of Carbon Nanotubes Power Delivery Networks for Nanoscale Integrated Circuits," in *IEEE Transactions on Nanotechnology*, vol. 15, no. 3, pp. 380-388, May 2016. doi: 10.1109/TNANO.2016.2535390.
10. J. Liang and A. Todri-Sanial, "Importance of Interconnects: A Technology-System Level Design Perspective", at *IEEE International Electron Devices Meeting (IEDM)*, San Francisco, CA, USA, 2019, pp. 23.1.1-23.1.4. doi: 10.1109/IEDM19573.2019.8993558.
11. B. Uhlig, A. Dhavamani, N. Nagy, . Lilienthal, R. Liske, R. Ramos, J. Dijon, H. Okuno, D. Kalita, J. Lee, V. Georgiev, A. Asenov, S. Amoroso, L. Wang, F. Koenemann, B. Gotsmann, G. Goncalves, B. Chen, J. Liang, R. R. Pandey, R. Chen, A. Todri-Sanial, "Challenges and Progress on Carbon Nanotube Integration for BEOL Interconnects," *IEEE International*

Interconnect Technology Conference (IITC), Santa Clara, CA, USA, 2018, pp. 16-18. doi: 10.1109/IITC.2018.8430411.

12. B. Uhlig, J. Liang, J. Lee, R. Ramos, A. Dhavamani, N. Nagy, J. Dijon, H. Okuno. D. Kalita, V. Georgiev, A. Asenov, S. Amoroso, L. Wang, C. Millar, F. Konemann, B. Gotsmann, G. Goncalves, B. Chen, R.R. Pandey, R. Chen, A. Todri-Sanial, "Progress on Carbon Nanotube BEOL Interconnects," *IEEE/ACM Design, Automation and Test in Europe Conference* (DATE), March 2018.
13. J. Liang, R. Ramos, J. Dijon, H. Okuno, D. Kalita, D. Renaud, J. Lee, V. P. Georgiev, S. Berrada, T. Sadi, A. Asenov, B. Uhlig, K. Lilienthal, A. Dhavamani, F. Könemann, B. Gotsmann, G. Goncalves, B. Chen, K. Teo, R. R. Pandey, A. Todri-Sanial, ''A Physics-Based Investigation of Pt-Salt Doped Carbon Nanotubes for Local Interconnects," *IEEE International Electron Devices Meeting* (IEDM), December 2017. doi: 10.1109/IEDM.2017.8268502
14. J. Liang, J. Lee, S. Berrada, V. Georgiev, A. Asenov, N. Azemard-Crestani, A. Todri-Sanial, "Atomistic to Circuit Level Modeling of Defective Doped SWCNTs with Contacts for On-Chip Interconnect Application," *IEEE Nanotechnology Materials and Devices Conference* (NMDC), October 2017.
15. J. Liang, A. Todri-Sanial, "Power and Performance Analysis of Doped SW/DW CNT for On-Chip Interconnect Application", *GRAPHENE 2017* International Conference.
16. J. Lee, T. Sadi, J. Liang, V. P. Georgiev, A. Todri-Sanial, and A. Asenov, "A hierarchical model for CNT and Cu-CNT composite interconnects: from density functional theory to circuit-level simulations," *IEEE International Workshop on Computational Nanotechnology* (IWCN) 2017.
17. J. Lee, S. Berrada, J.Liang, T. Sadi, V. Georgiev, A. Todri-Sanial, D. Kalita, R. Ramos, H. Okuno, J. Dijon, A. Asenov, "The impact of vacancy defects on CNT interconnects: From statistical atomistic study to circuit simulations," *International Conference on Simulation of Semiconductor Processes and Devices (SISPAD)*, Kamakura, 2017, pp. 157-160. doi: 10.23919/SISPAD.2017.8085288.
18. J. Lee, J. Liang, S. M. Amoroso, T. Sadi, L. Wang, P. Asenov, A. Pender, D. Reid, V.P. Georgiev, C. Millar, A. Todri-Sanial, A. Asenov, "Atoms-to-circuits simulation investigation of CNT interconnects for next generation CMOS technology," *International Conference on Simulation of Semiconductor Processes and Devices (SISPAD)*, Kamakura, Japan, 2017, pp. 153-156. doi: 10.23919/SISPAD.2017.8085287.
19. A. Magnani, M. de Magistris, S. Heidari, A. Todri-Sanial and A. Maffucci, "Electrical performance of carbon-based power distribution networks with thermal effects," *IEEE 21st Workshop on Signal and Power Integrity (SPI)*, Baveno, 2017, pp. 1-4. doi: 10.1109/SaPIW.2017.7944044.
20. J. Liang, L. Zhang, N. Azemard-Crestani, P. Nouet and A. Todri-Sanial, "Physical description and analysis of doped carbon nanotube interconnects," *International Workshop on Power and Timing Modeling, Optimization and Simulation (PATMOS)*, Bremen, 2016, pp. 250-255. doi: 10.1109/PATMOS.2016.7833695
21. A. Todri-Sanial, "Investigation of electrical and thermal properties of carbon nanotube interconnects," *International Workshop on Power and Timing Modeling, Optimization and Simulation (PATMOS)*, Bremen, 2016, pp. 25-32. doi: 10.1109/PATMOS.2016.7833421
22. A. Todri-Sanial, A. Magnani, M. de Magistris and A. Maffucci, "Present and future prospects of carbon nanotube interconnects for energy efficient integrated circuits," *International Conference on Thermal, Mechanical and Multi-Physics Simulation and Experiments in Microelectronics and Microsystems (EuroSimE)*, Montpellier, 2016, pp. 1-5, doi: 10.1109/EuroSimE.2016.7463379.