Bottom-up meets top down: An Integrated Approach for Future High Performance CMOS & Sensor Technologies

Dr. V. Ramgopal Rao, IIT Delhi
Fellow IEEE, FNAE, FNA, FASc, FNASc

Complementary Metal Oxide Semiconductor (CMOS) technologies are driving the Integrated Circuit (IC) markets. The conventional IC and the Micro-Electro-Mechanical System (MEMS) technologies usually employ top-down fabrication methodologies for high volume manufacturing. However, as the CMOS technologies are scaled down, there are many challenges owing to the variability, reliability and power issues. Similarly, though MEMS inertial sensors are sold in large volumes, the application of MEMS technologies for gas and bio-sensing is still ridden with reliability and selectivity issues. Some of these issues in CMOS & MEMS technologies can be better addressed by employing a host of bottom-up nanotechnology/biotechnology approaches through innovative process integration strategies. Further, in the current era of 'More than Moore' scaling, integration of diverse components/functionalities/processes on the chip dominates the technology roadmap rather than packing of more transistors on the die. This calls for an intelligent integration of diverse technologies, materials and processes on the same die for realization of future smart systems. Using examples [1]-[15], we will see how self-assembled monolayers can help extend the CMOS technology roadmap and help realize the future sensors needed for the Internet of Things applications.

References:

1. Mayank Shrivastava, V Ramgopal Rao, "A Roadmap for Disruptive Applications & Heterogeneous Integration using 2-Dimensional Materials: State-of-the-Art and Technological Challenges", Accepted for publication, ACS Nano Letters, July 2021
2. Shuchi Kaushik, Tejas Naik, M. Ravikanth, Che-Hao Liao, Xiaohang Li, V. Ramgopal Rao, Rajendra Singh, "Organic passivation of Al0.5Ga0.5N epilayers using self-assembled monolayer of Zn(II) porphyrin for improved solar-blind photodetector performance", Accepted for publication, Semiconductor Science and Technology (IOP Publishing), 2021
3. Priyanka Kumari, Jieun Ko, V. Ramgopal Rao, Subodh Mhaisalkar, and Wei Lin Leong, "Non-volatile Organic Transistor Memory based on Black Phosphorus Quantum dots Charge Trapping Layer", IEEE Electron Device Letters, Volume: 41 , Issue: 6, June 2020
4. Shuchi Kaushik, Tejas Naik, Ambali Alka, Manjari Garg, Bhera Tak, M. Ravikanth, V. Ramgopal Rao, Rajendra Singh, "Surface modification of AlN using organic molecular layer for improved deep UV photodetector performance", ACS Applied Electronic Materials, February 2020, pp.739-746
5. Priyanka Kumari and V. Ramgopal Rao, "Fermi Level Depinning in Germanium using Black Phosphorous as an Interfacial Layer", IEEE Electron Device Letters, VOL. 40, NO. 10, OCTOBER 2019
6. Richa Pandey, S. B.Gangadhar; Shivani Grover, Sachin Singh, Ankur Kadam, Satishchandra Ogale, Umesh Waghmare, V.Ramgopal Rao, Dinesh Kabra "Microscopic Origin of Piezoelectricity in Lead-free halide Perovskite: Application in Nanogenerator Design", ACS Energy Letters. 2019, 4,5, 1004-1011, March 2019
7. Manjari Garg, Bhera Tak, V. Ramgopal Rao, Rajendra Singh, "Giant UV Photoresponse of GaN-based photodetectors by surface modification using Phenol functionalized Porphyrin organic molecules", ACS Applied Materials & Interfaces, 2019, 11, 12, 12017-12026, March 2019
8. Manjari Garg, Bhera Ram Tak, V. Ramgopal Rao and R. Singh, "Enhanced Performance of Metal Semiconductor Metal UV Photodetectors by Molecular Modification of Gallium Nitride Using Porphyrin Organic Molecules", IEEE Transactions on Electron Devices, Volume: 66, Issue: 4,April 2019 Page(s): 2036 – 2039
9. Tejas R. Naik, Vibhas Singh, M. Ravikanth and V. Ramgopal Rao, "A Vapor Phase Self-Assembly of Porphyrin Monolayer as a Copper Diffusion Barrier for Back-End-of-Line CMOS Technologies" IEEE Transactions on Electron Devices, Volume: 63 , Issue: 5, Page(s): 2009-2015, May 2016
10. C. Vijaya Bhaskar Reddy, Mrunal A. Khaderbad, Sahir Gandhi, Manoj Kandpal, Sheetal Patil, K. Narasaiah Chetty, K. Govinda Rajulu, P. C. K. Chary, M. Ravikanth and V. Ramgopal Rao, "Piezoresistive SU-8 Cantilever with Fe(III)porphyrin coating for CO Sensing" IEEE Transactions on Nanotechnology, VOL. 11, NO. 4, JULY 2012

11. Mrunal Khaderbad, Verawati Tjoa, Manohar Rao, Rohit Pandharipande, Sheri Madhu, Jun Wei, M.Ravikanth, Nripan Mathews, Subodh Mhaisalkar, V.Ramgopal Rao, "Fabrication of unipolar graphene field effect transistors by modifying source and drain electrode interfaces with Zn-porphyrin", ACS Applied Materials and Interfaces, 2012 Mar;4(3):1434-9
12. Mrunal A. Khaderbad, Rohit Pandharipande, Vibhas Singh, S. Madhu, M. Ravikanth and V. Ramgopal Rao, "Porphyrin Self-assembled Monolayer as a Copper Diffusion Barrier for Advanced CMOS Technologies", IEEE Transactions on Electron Devices, VOL. 59, NO. 7, JULY 2012
13. Mrunal Khaderbad, Verawati Tjoa, Nripan Mathews, V. Ramgopal Rao and Subodh Mhaisalkar, "Facile fabrication of graphene devices through metalloporphyrin induced photocatalytic reduction" RSC Advances, Vol. 2, 4120-4124, 2012
14. M.A.Khaderbad, Urmimala Roy, M.Yedukondalu, M.Rajesh, M.Ravikanth and V.Ramgopal Rao, "Variable Interface Dipoles of Metallated Porphyrin Self-Assembled Monolayers for Metal-Gate Work Function Tuning in Advanced CMOS Technologies," IEEE Transactions on Nanotechnology, vol.9, no.3, Pages: 335-337, May 2010
15. Ravishankar S. Dudhe, S. P. Tiwari, Harshil N. Raval, Mrunal A. Khaderbad, Jasmine Sinha, M. Yedukondalu, M. Ravikanth, Anil Kumar and V.Ramgopal Rao, "Explosive vapour sensor using poly (3-hexylthiophene) and Cu-tetraphenyl-porphyrin composite based organic field effect transistors", Applied Physics Letters, Vol. 93, 263306 (2008)

Brief Bio of the speaker:

Prof. V. Ramgopal Rao is currently the Director, IIT Delhi. Before joining IIT Delhi as the Director in April 2016, Dr. Rao served as a P. K. Kelkar Chair Professor for Nanotechnology in the Department of Electrical Engineering and as the Chief Investigator for the Centre of Excellence in Nanoelectronics project at IIT Bombay. Dr. Rao has over 475 research publications in the area of nano-scale devices & Nanoelectronics and is an inventor on 48 patents and patent applications, which include 18 issued US patents. Thirteen of his patents have been licensed to industries for commercialization. Prof. Rao is a co-founder of two deep technology startups at IIT Bombay (Nanosniff & Soilsens) which are developing products of relevance to the society. Dr. Rao is a Fellow of IEEE, a Fellow of the Indian National Academy of Engineering, the Indian Academy of Sciences, the National Academy of Sciences, and the Indian National Science Academy.

Prof. Rao's research and leadership contributions have been recognized with over 30 awards and honors in the country and abroad. He is a recipient of three honorary doctorates. The recognitions Prof. Rao received include the Shanti Swarup Bhatnagar Prize in Engineering Sciences, Infosys Prize, IEEE EDS Education Award, Excellence in Research awards from IIT Bombay, DAE and DRDO, Swarnajayanti Fellowship award from the Department of Science & Technology, IBM Faculty award, Best Research award from the Intel Asia Academic Forum, Techno-Visionary award from the Indian Semiconductor Association, J.C.Bose National Fellowship among many others. Prof. Rao was an Editor for the IEEE Transactions on Electron Devices during 2003-2012 for the CMOS Devices and Technology area and currently serves on the Editorial Advisory Board of ACS Nano Letters, a leading international journal in the area of Nanotechnology. He is a Distinguished Lecturer, IEEE Electron Devices Society and interacts closely with many semiconductor industries both in India and abroad.

For more information about Prof. Rao's current research interests and a list of publications visit: http://www.ee.iitb.ac.in/~rrao/.