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Nanotechnology and Smart Materials for "More than Moore" – It's a Small World After All!

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Ever since Gordon Moore fore told about the future of the integrated circuit (IC) back in 1965 [1], Moore's law was not only an accurate forecast of the achievements that microelectronics community has made, but also was a yardstick of the appropriate level of the commercial development in microelectronics for the past five decades. Such an amazing pace of the IC technology development was possible essentially because of simple two-dimensional (2D) structure of the metal-oxide-semiconductor (MOS) field effect transistor (FET) invented by Hofstein and Heiman [2]. Putting more transistors in the same chip was possible simply by decreasing 2D feature size of the IC. The never-ending quest for ever and ever smaller feature size (another word, ever and ever increasing numbers of the transistors) in IC is stunning and gate insulation layer thickness today is only a few layers of oxide and the minimum feature size of the IC is sub-20 nm. While keeping this march becomes more challenging, there is no doubt that this amazing "more Moore" march will continue at least for a couple of more decades thanks to numerous innovations in materials, production technologies and a paradigm shift in design like FinFET [3]. However, "more Moore" by feature size reduction can only go so far and year after year we are getting one step closer to the physical limit.

In contrast to the spotlighted parade of "more Moore" [4], there have been rather humbling but steady stride of "more than Moore". While "more Moore" is basically miniaturization of electronics, "more than Moore" is integration and miniaturization of multiple functionalities "beyond" electronics encompassing mechanics, optics, biology, chemistry, etc. [5] "More than Moore" is in the same direction toward the vision casted by Nobel laureate Richard Feynman back in 1960 - "There's plenty of room at the bottom" [6]. In his seminal presentation, he mentioned about why and how of miniaturizing computer, biological system, tiny hands, and arrangement of individual atoms, among others. What is clear is that "more than Moore" is not an unintended byproduct of the "more Moore", rather it is a futuristic technology direction that just recently start to gain attraction. It is expected that more and more attention will be given on this new kid on the block, and this new stride will only be accelerated further and further as end-user consumer products require more and more value-added high performance multi-functionality "convergence" devices. Also, with the advent of another gigantic technology wave called "internet of things" [7], it is clear that "more than Moore" will be one of the crucial technology trends for the future. While nanotechnology and smart materials can be discussed in many different perspectives, as an editorial board member for the newly launching Journal of Nanotechnology and Smart Materials, I would like to contribute for the "more than Moore" aspect of the nanotechnology and smart materials. Needless to say, both nanotechnology and smart materials are absolutely important for the future innovations of "more than Moore".

There have been countless examples of the nanotechnology and smart materials, but I would like to briefly discuss one example each in the field of nanotechnology and smart materials that I have my expertise on. First example is nanophotonics, specifically tunable nano photonic crystals. Photonic crystals are artificially created "by design" structures in which different dielectric materials are arranged to form periodically varying dielectric constants throughout the structures. Since its invention by Yablonovitch in 1987 [8], photonic crystals have been one of the hottest research topics in the field of applied physics due primarily to numerous unique phenomena which were not observed in natural materials including negative refraction [9], super-lensing [10], super-prism [11], near-zero loss sharply bent waveguide [12], and slow light [13], etc. While there have been many fascinating demonstrations enabled by photonic crystals, adding on-demand reconfigurability to the photonic crystals would greatly expand existing application areas and potentially enable unforeseen new application areas. In order to make the photonic crystals tunable, modification of the spatial distribution of the dielectric constant would be needed. Electro-optic effect (modulation

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of dielectric constant of a material by applying electric field) and thermo-optic effect (modulation of dielectric constant of a material by changing temperatures surrounding the photonic crystals) [14] could be used to modify the spatial distribution of the dielectric constant and make the photonic crystals tunable. Another method of tunability is to induce physical dimensional changes in the lattice structure of the photonic crystal if the structures are composed of flexible materials [15]. In order to locally apply external control signals, the control units have to be integrated with the photonic crystals. Micro-Electro-Mechanical Systems (MEMS) technologies have great potential to provide a wide variety of radical options of tunability to the photonic crystal devices as they can be co-integrated with the photonic crystals. MEMS are ideally positioned in dimension to be integrated with photonic crystals for the wavelength ranges from the near infrared to terahertz. Nano-Electro-Mechanical Systems (NEMS), which is a branch of MEMS realizing MEMS devices with critical feature size in deep sub-micron scale can be potentially integrated with photonic crystals for the visible light spectrum. While there are numerous materials being studied as materials for the photonic crystals, silicon-based photonic crystals are expected to be the key technology for the future computing and data communications [16] because it will be seamlessly integrated with the CMOS IC technology.

Second example is liquid metal as an example of emerging smart material for “more than Moore”. Liquid metal is a metal that is in liquid phase at or near room temperature. Liquid metal has a wide range of applications due to its metallic property combined with its freely deformable liquid property. Mercury is the most well-known liquid metal, but its toxicity poses a threat to human health and environment. Recently, gallium-based eutectic alloys such as EGaIn [17] (a binary gallium and indium eutectic alloy) and Galinstan® (a ternary alloy of gallium, indium and tin) has emerged as an alternative to mercury because its toxicity is negligible [18]. In addition, they have higher boiling point, higher thermal conductivity, and lower electrical resistivity [19] compared to mercury. Based on these favorable material properties, gallium-based liquid metal alloys have been investigated for various applications including micro-cooling [20], deformable electrode [21], flexible electrical interconnection [22], microsyringe for cells [23], magneto-hydrodynamic (MHD) pump [24], flexible [25] and stretchable antenna [26], and tunable frequency selective surface [27] and filter [28]. Although gallium-based alloy has a great potential for a variety of promising applications, it is not without a problem. It is known that the surface of gallium-based alloy instantly oxidizes in ambient air environment and turns into a thin layer of gallium oxide (Ga_2O3 and Ga_2O) [29]. This oxide layer is solid and remains viscoelastic unless it experiences a yield stress, and thus the oxidized gallium-based alloy does not behave like a true liquid. Moreover, the oxide layer of gallium-based alloy adheres to almost any solid surface, causing a severe stiction problem. As mentioned, gallium-based liquid metal alloy has great potentials to be used in myriads of interesting and novel applications, but the instant oxidation is a difficult problem to overcome to say the least and device development using gallium-based liquid alloys has slowed down considerably. There have been a few studies to circumvent such a problem. Dicky et al. proposed a counterintuitive approach to utilize the stiction and the viscoelasticity to form stable microstructures in microfluidic devices [17]. Liu et al. found that Galinstan® does not oxidize when the concentration of oxygen in the surrounding environment is below 1 ppm [19]. Maintaining such an environment, however, requires a very tight and costly hermetic packaging. Zrnick and Swatik found that it is possible to remove the oxide layer by treating the surface with diluted hydrochloric acid (HCl) [30]. However, requirement of direct contact of HCl with the liquid metal undoubtedly limits applicability of this method in many practical applications. Kim et al. recently found that HCl vapor treatment is sufficient to remove the oxide skin of the gallium-based liquid metal alloy [31] which enabled oxide-free microfluidic platform for liquid metal [32] using HCl vapor diffused through gas permeable polymeric layer. It should be noted that while removal of the viscous oxide surface skin of gallium-based liquid metal alloys may be crucial for certain applications like micro switches, where the existence of a layer with high electrical resistance can compromise the performance of the device, in other applications such as heat transfer, MHD pump and FSS, increased electrical resistance at the surface is not a critical issue as long as liquid metal droplets or slugs are moveable without leaving any residue behind. Kim et al. recently reported that hierarchical micro/nano structured polymer surface can be used as a super-lyophobic surface and demonstrated anti-wetting microfluidic platform for naturally oxidized gallium-based liquid metal alloy [33]. It is expected that many creative approaches like those mentioned will eventually solve the nagging wetting problem and once it is fully utilized in micro fluidics and nano fluidics and integrated with other smart components, it will unleash the great potential of the liquid metal in many unforeseen innovative applications in the field of radio frequency (RF), biology and chemistry among others.

Although I discussed only a couple of examples here due to space limitations, I hope that the message is conveyed that nanotechnology and smart materials are crucial for future technology developments and it will directly and indirectly impact our everyday life sooner or later. I wish that this newly launching open access Journal of Nanotechnology and Smart Materials provides an agora where engineers and scientists working on the nanotechnology and smart materials all around the world freely get together and discuss.

References

1) G. Moore (1965) Cramming more components onto integrated circuits. Electronics 38: 08.

2) S. R. Hofstein, F. P. Heiman (1963) The silicon insulated-gate field-effect transistor. Proceedings of the IEEE. 51: 1190-1202.

3) E. J. Nowak (2013) Advanced CMOS Scaling and FinFET Technology. ECS Transactions. 9: 3-16.

4) http://www.itrs.net/Links/2012ITRS/Home2012.htm

5) W. Fang, Li S-S, Cheng C-L, Chang C-I, Chen W-C, et al. (2013) CMOS MEMS: A key technology towards the “More than Moore” era. The 17th International Conference on Solid-State Sensors, Actuators and Microsystems (TRANSDUCERS & EUROSENSORS XXVII). 2513-2518.

6) R. P. Feynman (1960) There's plenty of room at the bottom." Engineering and Science 23: 22-36.

7) Luigi Atzori a, Antonio Iera, and Giacomo Morabito (2010) The internet of things: A survey Computer Networks 54: 2787-2805.

8) Yablonovitch, E. (1987) Inhibited spontaneous emission in solid-state physics and electronics. Physics Review Letters. 58: 2059-2062.

9)Luo C, Johnson S G, Joannopoulos J D, Pendry J. B (2002) All-angle negative refraction without negative effective index. Physical Review. 65: 1-4.

10) P. V. Parimi, W. T. Lu, P. Vodo, and S. Sridhar (2003) Photonic crystals: Imaging by flat lens using negative refraction," Nature. 426: 404.

11) Kosaka H, Kaashima T, Tomita A, Notomi M, Tamamura T, et al. (1998) Superprism phenomena in photonic crystals. Phyical Review. 58: 10096-10099.

12) Chow E, Hietala, Joannopoulos, Lin S, Villeneuve P.R (1993) Experimental Demonstration of Guiding and Beding of Electromagnetic Waves in a Photonic Crystal. Science 8: 928-934.

13) Vlasov YA, O'Boyle M, Hamann HF, McNab SJ (2005) Active control of slow light on a chip ith photonic crystal aveguides. Nature. 438: 65-69.

14) Tinker M, Lee JB (2005) Thermal and optical simulation of a photonic crystal light modulator based on the thermo-optic shift of the cut-off frequency. Optics Express 13: 7174-7188.

15) Yonghao Cui, V. A. Tamma, Won Park, and J.-B. Lee (2010) Mechanically tunable negative-index photonic crystal lens", IEEE Photonics Journal. 6: 1003-1012.

16) Vlasov, Yurii A (2012) Silicon CMOS-integrated nano-photonics for computer and data communications beyond 100G. Communications Magazine, IEEE 50: 67-72.

17) Michael D. Dickey, Ryan C. Chiechi, Ryan J. Larsen, Emily A. Weiss1, David A. Weitz, et al. (2008) Eutectic Gallium-Indium (EGaIn): A Liquid Metal Alloy for the Formation of Stable Structures in Microchannels at Room Temperature. Advanced Functional Materials. 18: 1097-1104.

18) Galinstan fluid (2002) Galinstan Safety Data Sheet.

19) Tingyi Liu, Prosenjit Sen, and Chang-Jin (2012) Characterization of Nontoxic Liquid-Metal Alloy Galinstan for Applications in Microdevices," Microelectromechanical Systems, Journal of Microelectromechanical Systems. 21: 443-450.

20) Kun-Quan Ma and Jing Liu (2007) Heat-driven liquid metal cooling device for the thermal management of a computer chip. Journal of Physics D: Applied Physics. 40: 4722.

21)Hallfors N, Khan A, Dickey MD, Taylor AM (2013) Integration of prealigned liquid metal electrodes for neural stimulation within a user-friendly microfluidic platform. Lab on a Chip. 13: 522-526.

22) Hyun-Joong Kim, Chulwoo Son, Babak Ziaie (2008) A multiaxial stretchable interconnect using liquid-alloy-filled elastomeric microchannels. Applied Physics Letters. 92: 011904.

23)Knoblauch M, Hibberd JM, Gray JC, van Bel AJ (1999) A galinstan expansion femtosyringe for microinjection of eukaryotic organelles and prokaryotes," Nat Biotech. 17: 906-909.

24) Wasim Irshad and Dimitrios Peroulis (2009) A Silicon-Based Galinstan Magnetohydrodynamic Pump in PowerMEMS. 127-129.

25) G. J. Hayes, Ju-Hee So, Qusba A, Dickey M.D, Lazzi G (2012) Flexible Liquid Metal Alloy (EGaIn) Microstrip Patch Antenna. Antennas and Propagation. 60: 2151-2156.

26) Kubo M, Li X, Kim C, Hashimoto M, Wiley BJ, et al. (2010) Stretchable Microfluidic Radiofrequency Antennas. Advanced Materials. 22: 2749-2752

27) Meng Li, Bin Yu, Behdad N (2010) Liquid-Tunable Frequency Selective Surfaces. Microwave and Wireless Components Letters, IEEE. 20: 423-425.

28) Wenqi Hu, Ohta A.T, Shiroma W.A (2013) A reconfigurable, liquid-metal-based low-pass filter with reversible tuning," in Wireless Symposium (IWS), 2013 IEEE International. 1-3.

29) F. Scharmann, Cherkashinin V, Breternitz Ch, Knedlik G, Hartung, et al. (2004) Viscosity effect on GaInSn studied by XPS. Surface and Interface Analysis. 36: 981-985.

30) D. Zrnic and D. S. Swatik (1969) On the resistivity and surface tension of the eutectic alloy of gallium and indium. Journal of the Less Common Metals. 18: 67-68.

31) Kim D, Thissen P, Viner G, Lee DW, Choi W, et al. (2013) Recovery of Nonwetting Characteristics by Surface Modification of Gallium-Based Liquid Metal Droplets Using Hydrochloric Acid Vapor. ACS Applied Materials & Interfaces. 5: 179-185.

32) Li G, Parmar M, Kim D, Lee JB, Lee DW (2014) PDMS Based Coplanar Microfluidic Channels for the Surface Reduction of oxidized Galinstan. Lab Chip. 14: 200 – 209.

33) Daeyoung Kim, Dong-Weon Lee, Wonjae Choi, and J.-B. Lee (2013) A Super-Lyophobic 3D PDMS Channel as a Novel Microfluidic Platform to Manipulate Oxidized Galinstan. IEEE/ASME Journal of Microelectromechanical Systems. 22: 1267-1275.