Democratized Electronics To Enable Smart Living For All

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***Abstract*—With the increased global population, smart living is an increasingly important criteria to ensure equal opportunities for all. Therefore, what is Smart Living? The first time when we tossed this terminology seven years back, we thought reducing complexities in human life. Today we believe it more. However, smart living for all complicates the technological need further. As by all, we mean any age group, any academic background and any financial condition. Although electronics are powerful today and have enabled our digital world, many as of today have not experienced that progress. Going forward while we realize more and more electronics in our daily life, the most important question would be how. Here we show, a heterogeneous integration approach to integrate low-cost high performance interactive electronic system which are physically compliant. We are redesigning electronics to redefine its purposes to reconfigure life for all to enable smart living.**

Keywords—CMOS electronics; flexible; stretchable; silicon.

I. Introduction

Recently Internet of Things (IoT) have emerged as the new electronic technology trend to monitor environment and its various components (both biological and artificial). While the prediction is for trillions of sensors by 2030, there are several technological challenges remain unsolved yet to realize such vision. They include but not limited to: (i) device design; (ii) energy efficiency; (iii) deployment ease; (iv) communication protocol; (v) affordability and (vi) data management (including data protection). Interestingly all these requirements are all connected to the physical electronics. As an example: we prefer the devices to be integrated, small size, portable, light weight and possibly flexible and stretchable to conform to no-uniform body contour, asymmetric surfaces of soft skins and tissues. While miniaturization has been the key to drive the digital age, miniaturized alone cannot solve the conformity issue as discrete device requirement of rigid to flexible printed circuit board keep the challenges still looming. Therefore, in this paper, we discuss our views and technological progresses we have made to address these challenges and translating laboratory innovations into technologies [1-3]. Obviously to serve purpose of the specific focus session theme on smart living, we will focus on a few examples which dramatically reduce the complexities in life and augments the quality of life.

II. Perspective and Processes

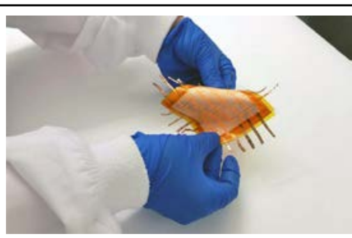
Presently 90% of the electronics are made with bulk silicon (100). And like them, other kind of crystalline materials which are used for broad range of electronics fabrication are rigid. While they have been consistently scaled down in their geometric foot prints, yet the caged Integrated Circuits (ICs), mica capacitors and resistors are still rigid and fairly large. Specially the complex one with large fan-puts have multiple pins to be soldered or bonded with the rigid PCBs to have a full-fledged electronic system. We are not yet considering the power supply (means battery and probably integrated with energy harvesters). Therefore, overall system eventually remains rigid. Although some research groups have suggested usage of flexible PCBs, they have limited bendability, the intimate contact with electronic components are shaky and localized hot spot creation are common observations from such pseudo-flexible systems. In that regard, we have been successful to use complementary metal oxide semiconductor (CMOS) compatible processes to transform any traditional rigid ICs (mainly silicon, silicon germanium, germanium, III-V materials based electronics) into flexible one while retaining their performances, energy efficiency, ultra-large-scale-integration density and cost effectiveness. We use reactive ion etching and sacrificial thin films to form an array of porous network within the substrates, followed by selective peel off of the top ultra-thin portion of the substrates with pre-fabricated electronics. Next, we perform chemical mechanical polishing to recycle the remaining substrates multiple times. This way, we have been able to achieve 0.5 mm bending radius ultra-thin (5 μm) bulk silicon (100) with sub-20 nm wide fins (high performance FinFETs), VLSI ferroelectric random access memory (FeRAM) with 1 billion cycles of retention, large area (36 square inch) photovoltaic cells with record 18.5% efficiency, micro-lithium ion battery with large capacity (3500 μAh) and cycling (120 cycles). Additionally, we have demonstrated fractal design based ultra-stretchable electronic platform where silicon can be stretched up to 1000% with bending radius down to 0.25 μm. All these demonstrations comprise of integrated array of electronics and complex circuitry. Additionally, for the first time we have shown multi-sensory platforms with full conformity of the entire electronic system. Such conformity allows the sensors to be in intimate contact with the user's skin or tissue surfaces. Moving further, we have also tested its bio compatibility and biodegradation as needed. All these studies allowed us to build a big database of materials, geometry, device design, processes, mechanical and electrical properties and their interrelationship.

While CMOS electronics will play continued catalytic role in interface electronics, in future it might be possible to have sensors built with 2D materials (graphene, dichalcogenides) and actuators with 1D materials (like nanowires and nanotubes). We also believe it is fundamentally important to reduce the antenna size while preserving its performance under various mechanical deformation due to the overall flexible and stretchable nature of the system. While we have demonstrated such out-of-plane stretchable antenna with operation frequency 2.45 GHz at a distance of 390 meters (which suffices far-field communication), still further progress needs to be made.

Since, overall traditional device community and VLSI community are specifically focused on power savings and energy efficient electronic system design, we will skip any narrative on those except the fact that their proposed and demonstrated design(s) based ICs can be easily flexed and stretched using our processes. At the same time, we would like to attest that significant pragmatic progress is needed in context of power management. As of today, energy storage capability is volumetric (both from area and weight perspective). Therefore, without dramatic change it will be difficult to achieve energy independence at nano-scale. Also, except photovoltaic technology, other kind of energy harvesting techniques (like thermoelectric, RF, piezoelectric) are yet to prove their increased efficiency and effectiveness to meet the overall sustained energy requirement of gradually complex circuitry and systems.

It is often dubbed that, organic and molecular electronics can be good replacement of traditional crystalline materials (like silicon, silicon germanium, germanium, III-V, etc.) as flexible and stretchable electronic system, without much progress in their thermal stability, electron transport capability, it will be a remote dream to realize such system.

Having said that, we have focused on two specific visions: affordability and ease of deployment. If we carefully observe the technology trend, most of the high tech gadgets are limitedly used by consumers who can afford them. Therefore, without drastic reduction in price it would be impossible to impact more people’s life. And that’s why we have specifically focused to categorically reduce the number of components, expensive materials and processes. As an example, in 2016, we demonstrated (multiple times) non-functionalized household paper based electronic skin. For the first time, we used both in-plane and out-of-plane (3D) integration to mimic human skin and its functionalities. The sensory platform included pressure, temperature, strain, humidity, photo, flow sensing and by 3D integration, it was possible to simultaneously sense variety of



stimuli. Such move allowed us to reduce the cost of the electronic system significantly (one fourth of a conventional equivalent electronic system).

Another aspect is to ease deployment means how we can empower everyone to use low-cost easy to learn and simple to implement and use electronics. Therefore, we have redesigned conventional rigid ICs into decal electronics with variety of options for easy integration (like Lego like assembly).

III. Technology Translation

As of today we have been successful to engage more than 10 non-electronics industry giants to use redesigned electronics. Such industries are mostly healthcare based, arts industry, civil infrastructure automation companies. As an example, we have developed smart thermal patch, which is a stretchable copper based platform and precisely provide thermotherapy based on Joule’s Heating Effect using flexible CMOS interface electronics. Another example is paper watch, which can monitor blood pressure, heart rate, temperature and skin hydration but from cost perspective it costs less than $20. Our present objective is to add GPS capability and reduce the price down further. To combat drug overdose related challenges, we have developed ultra-low cost safe pill decal which integrated with medicinal container, immediately notifies the caregivers in case of overdose attempt or such.

Going forward, we certainly believe that multi-disciplinary effort will empower us to think innovatively and to provide affordable technological solution to everyone. And that will need comprehensive engineering based integration of simple solutions into standalone electronic platform.

IV. Conclusion

In this paper we have discussed our perspective and processes on redesigning electronics to redefine their purposes to reconfigure human life. We consider, electronics can play more critical role to augment the quality of our life. Question is are we thinking in the right direction? Are we thinking out of the box within the boundaries?

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