Stretchable Hybrid Electronics for High-Performance On-skin Electronics

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ABSTRACT

Key enabling technology for stretchable hybrid electronics, including strain-engineered elastic platform and integration of rigid high-performance devices with printed soft components, will be discussed. Several prototypes based on the developed technology will be presented for display, sensor, UI/UX, and thermoelectric applications.

1 Introduction

A platform technology based on stretchable substrate has gained a lot of attention in wearable electronics area. [1] Highly conformable property of the stretchable platform makes itself the most promising candidate for body-attachable or multi-curvature-surface-attachable wearable applications. However, integration of conventional rigid but high-performance devices on such a new platform is still challenging. Strain engineering with proper chip bonding strategy is a key enabling technology for expediting commercialization of stretchable wearable technologies. So-called stretchable hybrid electronics (SHE) technology, as shown in figure 1, will make possible an unprecedented form of smart skin that has extreme conformability on various undulating surfaces including human body. When it is used for bio applications, it provides much improved functions in detecting body movement or bio signals, displaying information and even powering wearable devices. In this talk, some of progress achieved in my group will be shared in applications of display, sensor, UI/UX, and thermoelectric battery.

2 Strain Engineering

Since high-performance devices such as silicon chips, LEDs, and lumped elements are rigid, they need to be protected from damage under mechanical deformation when they are integrated in a wearable electronic system. One example is inserting printed rigid islands into elastic soft substrate as shown in figure 1 so that they can protect the rigid components that are to be placed on them under mechanical deformation. The strain curve graph shows that the level of strain that the active device region has been much lowered by the embedded rigid islands and major strain is applied to the stretchable electrodes. In order to simplify the strain engineering but with the same protection effects, pure epoxy banks can be also additionally printed during printing silver epoxy for chip bonding process. The banks play the same role as the rigid islands and effectively protect rigid components and bonding area from external stress during mechanical deformation process [2]. With the technology of stretchable electrodes, the strain-engineered soft substrate allowed for transforming a conventional printed circuit board into a stretchable one.

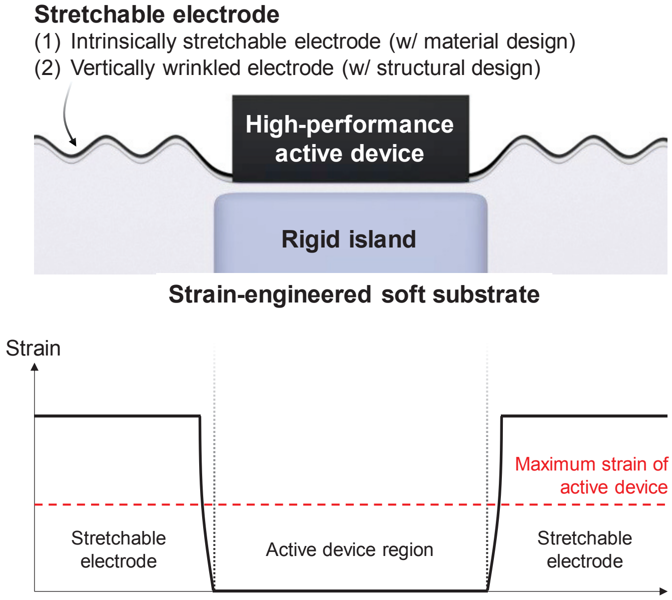

Figure 1. Stretchable Hybrid Electronics (SHE): strain-engineering and stretchable interconnects, and strain distribution of the engineered soft substrate

3 Stretchable Electrodes (Interconnects)

The highly functional, typically rigid and brittle, conventional components are isolated from any external deformation stress, by placing stretchable interconnect conductors in between. In order to integrate conventional rigid components on the strain-engineered platforms, such as surface mount devices (SMDs), light-emitting diodes (LEDs), lumped components, integrated circuit

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chips, and thermoelectric legs (Bi-Te TE legs), we place the rigid component on the strain-engineered platform and connect them with either inkjet-printed or spray-coated silver-based electrodes. Our group is using both structure- and material-design approaches considering properties of used materials as shown in figure 1. For silver thin-film electrodes, vertically-wrinkled structure is introduced so that the electrode does not lose its conductivity under stretching deformation. The vertical structure is formed by printing silver electrode on the pre-stretched soft substrate. When the applied pre-stretching is released, vertically-wrinkled silver electrodes are formed. We also use silver nanowire materials for the stretchable interconnects, where mesh-like structure of the nanowire networks can maintain the conductivity under stretching deformation. In order to further improve the performance of stretchable electrodes, the vertically-wrinkled structure can be also implemented for the silver nanowire network. Such a combination of material- and structure-design electrodes showed excellent performances in stretchable wearable electrode systems.

4 System Integration

For array-form electronic system integration we need to have a certain way to provide electrical conduction or insulation between two or more cross-over electrodes. We developed stretchable-via and double-side PCB based on the via and printed crossover insulators that sustain under stretching deformation. [2] Recent progress in stretchable-via technology allowed us for implementation of multi-layered PCBs. We also developed a new strategy for body attachable devices. Instead of handling individual element, using soft electronic modular blocks (SEMBs) consisting of groups of same functioning elements, which are circuit blocks of sensors, displays, electrodes and micro-processors, we directly assembled the modular blocks on body surface and developed a fully customized wearable MP joint flexion monitoring system with high measurement accuracy [3].

5 Future Prospect

For a long-term solution toward low-cost and potentially disposable wearable devices, we are also working on stretchable printed electronics technology, focusing on stretchable electrodes and pressure/strain sensors [4]. SHE and printing technologies would make paradigm shift of wearable electronic devices and help electronic skins and stretchable patch devices emerging in market as early as possible

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