Flexible Hybrid Electronics on Wearable Healthcare Application

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***Abstract*—24/7 real-time body signal monitoring for decease check and life quality enhancement is becoming a megatrend these years. However, the precious yet limited clinical facility and medical professionals cannot fulfill the emerging needs out-of-hospital. A wearable device such like smart watch utilizing biosensor-integrated System-in-Package (SiP) module can provide a real time and personal-based bio data collection as well as better health management through AI assistance. For performing a more comfortable experience, flexible hybrid electronics with ECG SiP embedded was proposed with lower profile and higher structure flexibility. The patch durability by 100,000 times rolling test as simulating daily use condition was also examined.**

Keywords — Flexible Hybrid Electronics (FHE), System-in-Package (SiP), Electrocardiography (ECG), Patch

I. Introduction

Wearable electronics empowered by System-in-Package (SiP) technology become wide spread for almost all time and immediate communication as well as bio-information could be analysis through AI for instant care, especially in post pandemic era of COVID-19. However, current wearable electronics, such like smart watches and smart earbuds, with rigid hard case in appearance achieved bio signals harvest through a proximity and unstable interface make a poor signal-to-noise ratio and limited stich time and located at terminal of human body. Main bio-signals from heart and lung, which are central of circulation and respiration system respectively, can still be monitoring through either hospital based complex system or tight fasten sensor box link to portable systems under special clinical care and comment by doctors. Unfortunately, most of sudden disease occurred and fatal accidence cannot be alarmed in the scheduled time of monitor system utilizing. A 24/7 wearable solution for bio signal monitoring through extendable sensors integration as well as wireless module obtains signal access to nearby mobile phone for providing instant care and health analysis becoming an emerging issue. Current wearable ECG product, as shown in Fig. 1(a), with thick & rigid appearance induce a foreign body sensation and bondage while use. New concept for sensors on skin draw a great attention and various approaches were proposed [1-6] which mostly stayed at research stage.

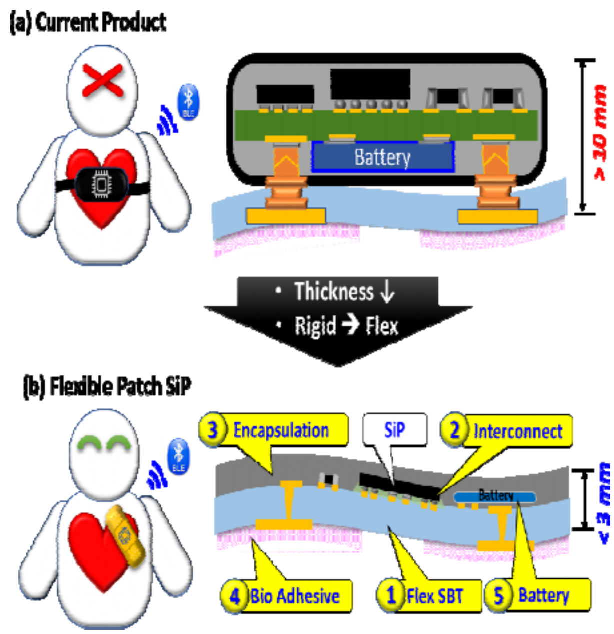

Fig. 1. ECG product as exeample. (a) current ECG product with rigid, thick and belt fasten for long time health monitoring ; (b) Flexible patch SiP provide a comfort experience for use.

In this study, a patch-type flex SiP with slim and bendable structure coat with flexible and bio compatible encapsulant, illustrated in Fig. 1(b), was considered as an achievable solution to market. This patch achieved through 5 key process technologies including a 2-layer flexible printed circuit (FPC), interconnect material for surface mount technology (SMT), flex encapsulation, bio-adhesive for patch immobilize and bio signal transportation as well as the feasibility of embedded battery in SiP. Moreover

The examination criteria of patch was setting as pass rolling test for 100,000 times in R ≤ 60 mm which adapt to required curvature of human chest without structure delamination and ECG monitoring showed clear signal character that comparable to result of conventional 1-lead system. In order to reduce foreign material sensation, the total thickness should be reduced to less than 3 mm.

II. EXPERIMENTAL

A. Flexible Printed Circuit

Flexible printed circuit composed by substrate polymer and conductive pattern with redistribution layer (RDL) and pad for component landing. Substrate polymer was mainly focus on polyimine (PI, thickness = 150 um) material due to bendable property and wide spread in electrical package application. Conductive material was electroplating copper (EP-Cu) as reference and new silver pastes with printing process as alternative solution for higher process flexibility on prototyping and integration feasibility study. 2 kinds of silver pastes utilized for stability test. Ag paste A (AT-XB80, Giga Solar Materials, Taiwan) composed with silver particle in micro size and Ag paste B (RD0117B, ACI Materials, US) composed with nano/micro particle mixture, respectively.

B. Interconnection

The interconnection was formed through surface mount technology in this study. Daisy-chain die (2 types: 4.2 x 4.2 mm^2 and 8.4 x 8.4 mm^2 with pad diameter = 150 um in both cases) and passive components (0603 in size of 1.6 x 0.8 mm^2 ; 0201 in size of 0.6 x 0.3 mm^2) were mount onto designed FPC. Due to reduce thermal damage and lower shrinkage under polymer substrate process, interconnect material curing temperature setting 150°C in maximum. The interconnection material in this study including low temperature solder paste (T6, Heraeus, Germany) and Ag paste C (TM1079, ACI Materials, US). Underfill (HiTech CU13-3150, MacDermid Alpha, US) in some cases was applied at the die bottom for increasing die strength during rolling test.

C. Encapsulation

Epoxy molding compound (EMC) play a key role for package protection and component isolation. Conventional EMC with high modulus in range of 5~30 GPa perform a rigid and high stiffness and not suitable for Flex SiP application. Silicone with tunable and extremely low modulus (1~100 Mpa) as well as high chemical resistance and bio-compatible was considered for encapsulation material. In this study, silicone with modulus < 30 Mpa (RTA4024, Howren, Taiwan) was focused for rolling durability test.

D. Bio-adhesive

The customized designed bio-adhesive tape composed with adhesive tape and conductive hydrogel in which electrical signal of ECG can pass through RDL and accessed to SiP module. System integration test by check character signal of ECG was obtained.

E. Battery

Lithium Polymer (Li-Po) with flexible and slim shape show a great potential for battery embedded ; Button cell battery (also called "Coin battery") is another candidate due to relative high power density and compact size. The battery with DC 3.7 V and capacity should larger than 200 mAh were defined for stable power supply in 1-week wearable use.

F. Roller test machine

Rolling test in this study was achieved in Yuasa's desktop model endurance system (Yuasa System Co., Japan). The test condition of rolling radius was in range of 1.5~60 mm with 50 rpm and loading in 500 g. Rolling criteria was 100,000 times.

III. RESULTS AND DISCUSSION

To realize patch-type flex SiP, material selection of substrate and interconnection would be most critical and should be clarify by step. Structure protection / strengthen material such as underfill and encapsulant were derived a synergy performance with substrate and interconnect material. Bio-adhesive and battery solution as peripheral infrastructure affect the system integration level as to application condition.

A. Bare FPC for Rolling Test

In order to meet rolling criteria, RDL design for robust electrical transmission structure was studied. 4 types printing wire with various line width and shapes were considered. As Fig 2, Type 1 was straight line with width 0.3 mm; Type 2 was also straight but larger width of 0.5 mm; Type 3 and Type 4 were the same width to Type 1 but different shape. These non-straight shape were for reducing bending stress and prevent line crack.

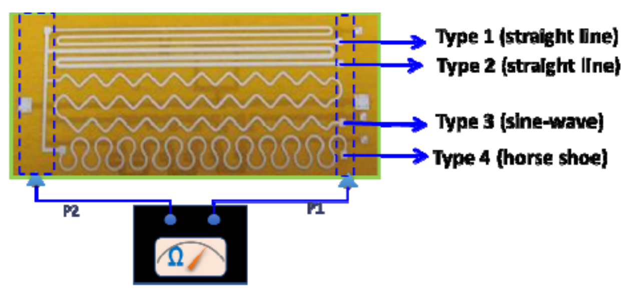

Fig. 2. RDL design test with various line type: Type 1 (Straight / width 0.3 mm) ; Type 2 (straight / width 0.5 mm) ; Type 3 (Sine-wave / width 0.3 mm) ; Type 4 (horseshoe / width 0.3 mm)

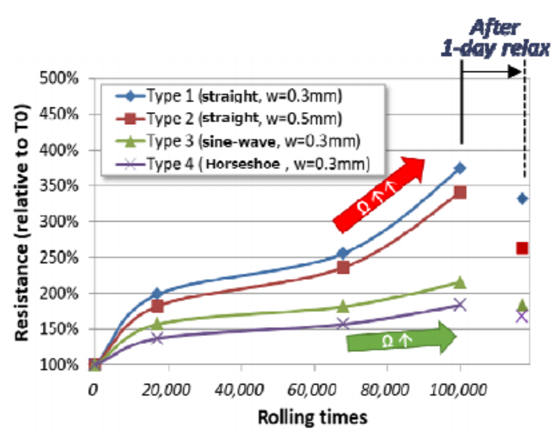

Fig. 3. RDL resistance increasment relative to T0. Type 3 and Type 4 perform a relative lower resistance change and betterstability after 15-hr relaxing.

The resistance change result as shown in Fig. 3. For line width comparison in Type 1 and Type 2, the resistance increasing trend is the same, means line width cannot provide a stable RDL. For various line shape in Type 1, Type 3 and Type 4, both sine-wave and horse shoe could significant inhibit the resistance increase in higher rolling times where were also less resistance change after 15-hr relaxing. As considering of design difficulty and high density request, sine-wave pattern should be a better choice than horse shoe.

An alternative RDL process of conductive paste printing was further studied since current EP-Cu RDL with longer process time and resource consumption in lithography and wet etching steps. Various Ag pastes was applied with sine-wave shape and compare to EP-Cu as reference. Paste A composed with micro size Ag particle where Paste B was mixture of nano/micro particle and obtain a lower contact resistance, the sample prepared as shown in Fig. 4. The resistance change was shown in Fig 5 and Paste A with single micro Ag particle obtain not only a high resistance at T0 but also resistance instability after rolling test. Paste B perform a comparable result to EP-Cu under the same rolling times and it would be more process application for using paste printing process on new flex patch.

B. *Rainforced FPC for Rolling Test*

Bare FPC could be exist in system while playing as a RDL layer. As talk to components mounting and interconnect formation, underfill and encapsulation were required in following process in real application. In this section, a high density SMT with daisy-chain dies and passive components was achieved on EP-Cu/PI substrate and 2 types of interconnect material including Ag paste C and low temperature solder were utilized. The test vehicle with SMT process as shown in Fig. 6(a) and the resistance monitoring for die and passive components was separated due to different challenge and possible underfill applied at die bottom. In case of underfill apply, shown in Fig. 6(b), the gap for underfill filling is 120 um. As patch encapsulated with silicone, the test piece would proceed rolling test as setup in Fig. 6(c).

In Fig. 7, low temperature as interconnect with silicone encapsulant, no matter underfill applied or not, perform a stable resistance status even up to 100,000 times rolling. However, in Ag paste C cases, insufficient structure strength without underfill induced a rapid fail. In material aspect, low temperature solder with better stiffness than Ag paste C and underfill support can enhance the system durability while Ag paste used.

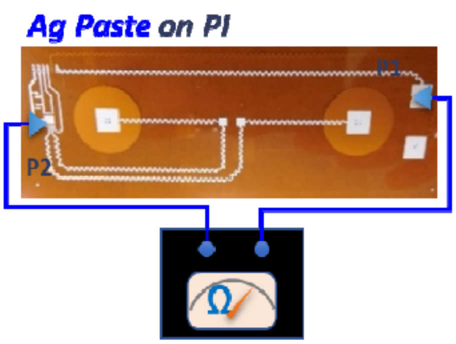

Fig. 4. RDL materials comparison in sine-wave shape of ECG patch: A sample build.

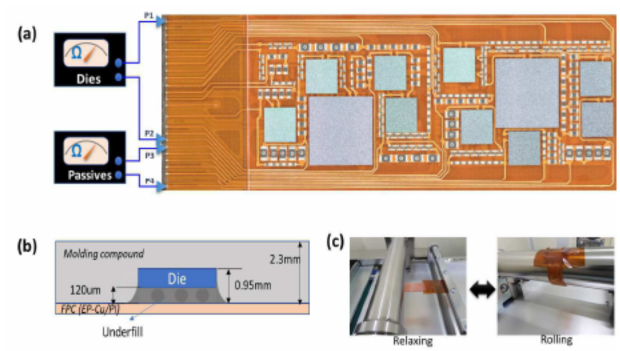

Fig. 6. Test vehile for high desity daisy-chain die and passive component with silicone encapsulated: (a) resistance monitoring setup; (b) test vehicle cross-section view; (c) rolling test setup.

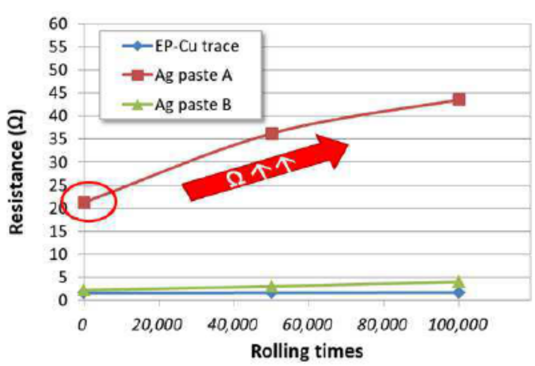

Fig. 5. Resistance increasement of various RDL material. Paste B with more stable resistance than Paste A.

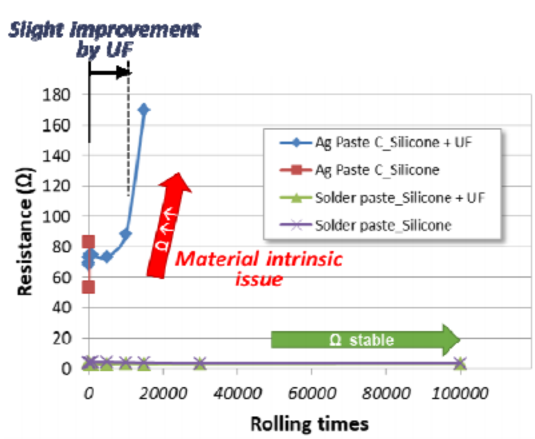

Fig. 7. Resistance chage under different structure.

C. Bio-adhesiive Integration

Bio-adhesive composed with adhesive and hydrogel was designed to fit the test vehicle in this study. Conventional ECG product was utilized for the new patch interface evaluation. Bio-adhesive taping on FPC and paste to human body; the electrical signal connection was through welding line between FPC and ECG module, as shown in Fig. 8. The character wave of ECG signal can be observed in this test. However, the signal to noise ratio was poor due to circuit impedance was not optimized and it would be addressed in integrated system.

D. Embedded Battery Solution

Power solution is the last mile to realize fully functioned wearable system as well as whole module size and persistent usage was limited to the battery size and energy capacity. In this study, Li-Po battery with thin (~ 1 mm) and flexible appearance was try to embedded into patch for rolling test. The low temperature encapsulation curing at 85°C can provide a feasible process to Li-Po integration. When rolling test upto 90,000 times, the embedded Li-Po battery became inflate and the output voltage was reduced, as in Fig. 9 where the rechargeable test monitoring as shown in Fig. 10.

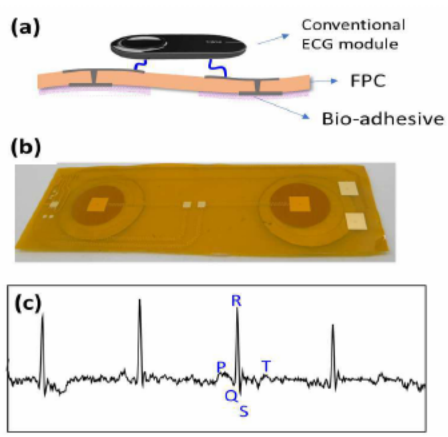

Fig. 8. Bio-adhesive functional test. Bio-adhesive on FPC form a new interaface between cnventional ECG module and human body for ECG signal reading.

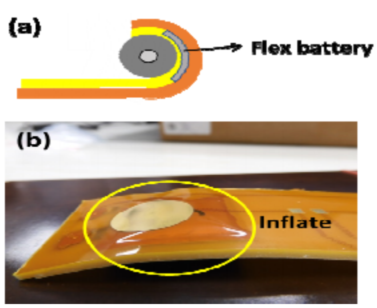

Fig. 9. Li-Po battery embedded in encapsulation of patch. After 80,000 rolling, the battery become inflate and voltage dowm.

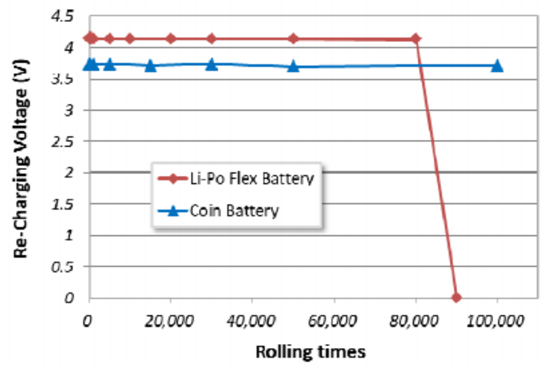

Fig. 10. Embedded battery rechargable under various rolling rounds.

IV. Conclusions

FHE for long time wearable in categories of iPatch (bendable) and iCloth (stretchable) were considered as shown in Fig. 11. Patch-type flex SiP, as first step demonstration, provided an attractive platform to reach the requirement. The capability criteria was highly correlated to the usage scenarios. ECG module for example, the radius R of patch bending curvature would be several tens mm for taping on chest but only few mm of R while access the bio-signal of finger. The durability criteria such as times and test mode (e.g. rolling, bending, twisting, etc.) be also considered. Moreover, different FPC deformation modes including bendable and stretchable should be defined before flex patch development for specific application. Patch-type flex SiP for ECG measurement could be realize by modifying current EP-Cu/PI FPC with low temperature solder for components mount as well as silicone encapsulation provide a module protection and flexible interface. The verification of integrated system would be scheduled for next study.

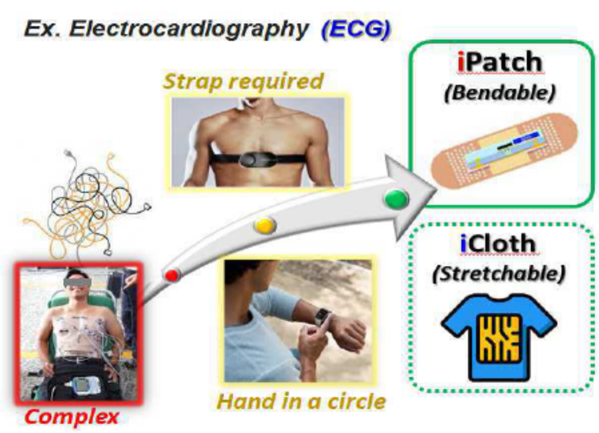

Fig. 11. FHE application for long-time wearables: ECG monitoring as eamaple where bendable (iPacth) and stretchable (iCloth) ideas were proposed.

REFERENCES

[1] C. Falconi, and S. Mandal, “Interface electronics: state-of-the-art, opportunities and needs,” Sensors and Actuators A: Physical, vol. 296, pp. 24-30, 2019.

[2] D. Corzo, G. Tostado-Blázquez, and D. Baran, “Flexible electronics: status, challenges and opportunities,” Frontiers in Electronics, vol. 1, 594003, 2020.

[3] S. P. Lee, G. Ha, D. E. Wright, Y. Ma, E. Sen-Gupta, N. R. Haubrich, and R. Ghaffari, “Highly flexible, wearable, and disposable cardiac biosensors for remote and ambulatory monitoring,” NPJ digital medicine, vol.1 (1), pp. 2, 2018.

[4] Q. Li, J. Zhang, Q. Li, G. Li, X. Tian, Z. Luo, and J. Zhang, “Review of printed electrodes for flexible devices,” Frontiers in Materials, vol. 5, pp.77, 2019.

[5] Y. Wang, C. Xu, X. Yu, H. Zhang, and M. Han, “Multilayer flexible electronics: Manufacturing approaches and applications,” Materials Today Physics, 100647, 2022.

[6] W. Wu, “Stretchable electronics: functional materials, fabrication strategies and applications," Science and Technology of Advanced Materials, vol. 20(1), pp. 187-224, 2019.