Recent Advances in Anisotropic Conductive Films (ACFs) Technology for Wearable Electronics

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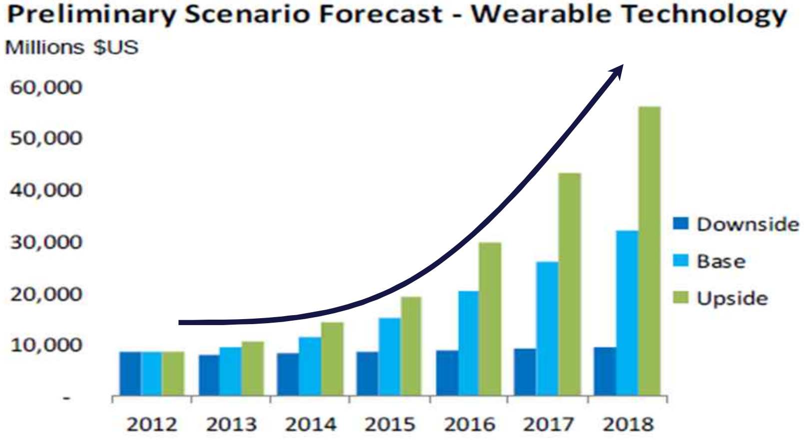
1. Wearable Market trends

Wearable device in movies

Now, start wearble device war


Preliminary Scenario Forecast - Wearable Technology

Source: IHS Inc. September 2013

Wearable electronics trends

Convergence to Smart Phone

Divergence to wearable device

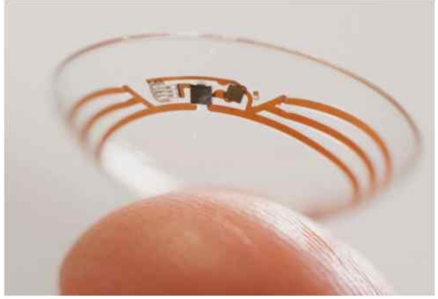
- **Wearable devices perform subsidiary functions of smart phone by using wireless network.**

* Reference : 2014 웨어러블 디바이스 산업백서(KT 경제 연구소)

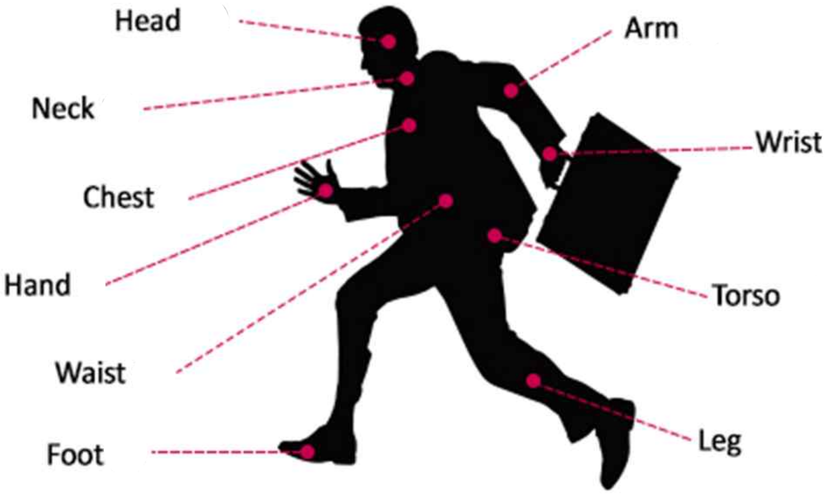
Trends in wearable electronic devices

Ref)
Google glass : https://www.google.com/glass/start/
Smart contact lens : http://googleblog.blogspot.kr/2014/01/introducing-our-smart-contact-lens.html
Galaxy gear : http://www.samsung.com/us/mobile/wearable-tech/SM-V7000ZKAXAR
MC10 sensor : http://www.mc10inc.com/

<Google glass>



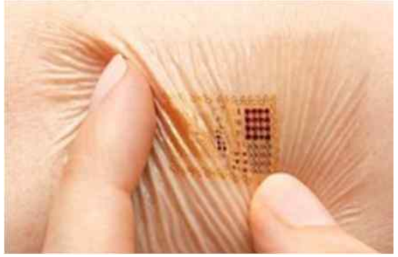
<smart contact lens>



wearable devices for each body parts

- ✓ ***Miniaturization***
- ✓ ***Light weight***
- ✓ ***Flexibility***
- ✓ ***Reliability***
- ✓ ***High performance***

<Galaxy gear>



<MC10 sensor>

Trends in wearable electronic devices

Source) Nike

Nike-google fuel band

Flexible package is necessary
for wearable electronic devices

1. Wearable Market trends

- What is current wearable applications?

Wearable application

Healthcare & Medical

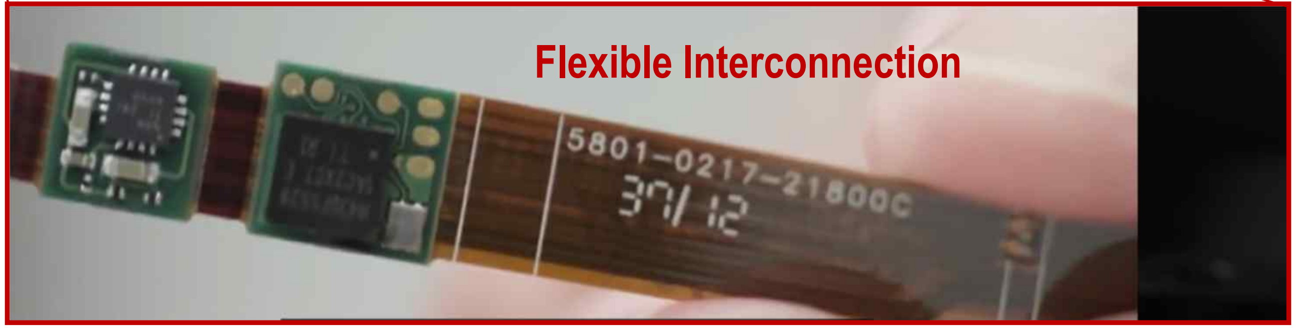
Fitness & Wellness

Industrial & Military

Infotainment

1-1. Fitness and Wellness - Bracelets

○ Bracelets Teardown (Jawbone)

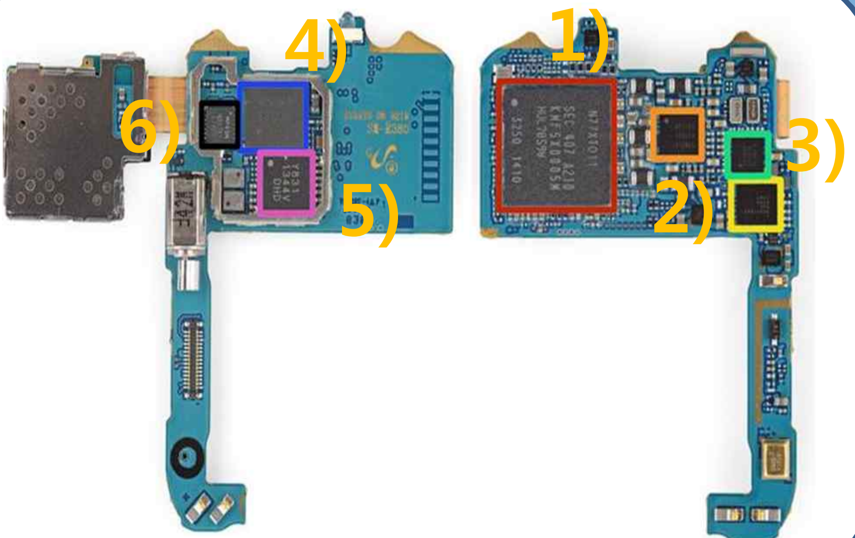


Rigid Substrate locate the right location to avoid bending reliability issues

The Interconnection is connected by FOB between Rigid and FPC.

1-2. Informative Device - Smartwatch

Tear-down of galaxy gear 2



1. Samsung KMF5X0005M AP
   (DRAM package, 1 GHz dual-core CPU)
2. Maxim Integrated MAX77836
   (likely micro-USB interface controller and battery)
3. STMicroelectronics 32F401B
   32 bit ARM Cortex MCU
4. 0225E8 E225B4
5. BCD Semiconductor Y831 audio code
6. InvenSense MP65M
   6-axis gyroscope / acceleromete

1-2. Informative Device – Smart Glass

○ **Google Glass**

- **Competitor : Samsung Gear Glass Launch (2014, 2Q)**

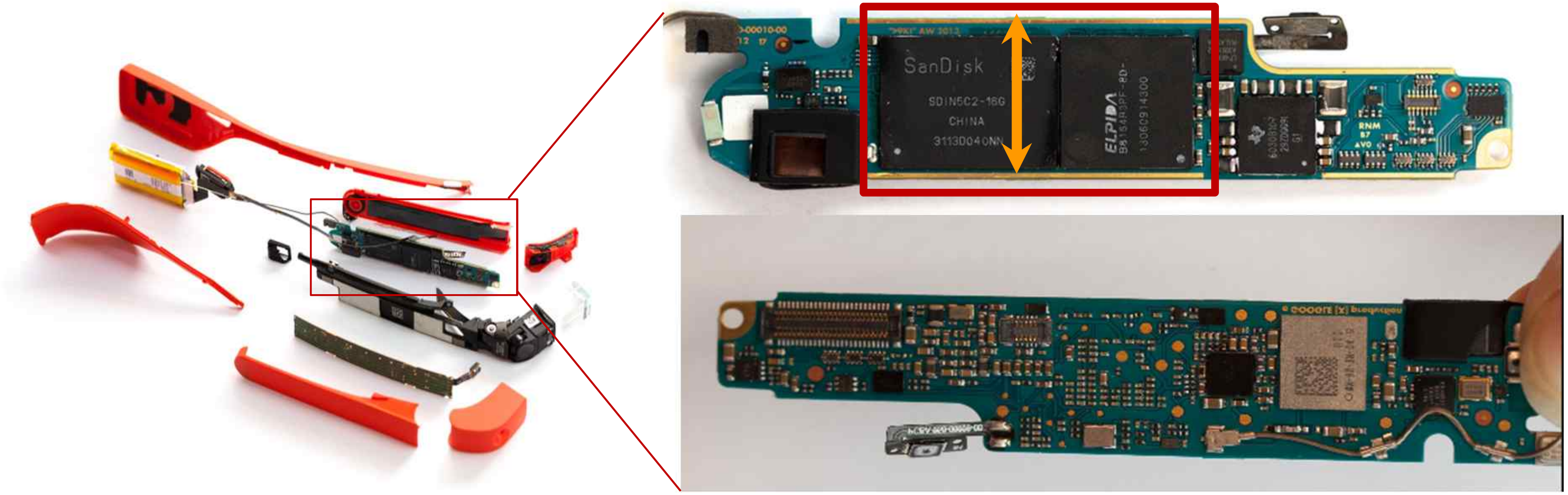
Add Substructure to the glasses

Item	Component	Remark
S/W	**Android**	**4.0.4**
Display	**640×360 display**	nHD (640 x 360) Display
Active Device	**AP**	**Texas Instruments OMAP 4430 SoC** **1.2Ghz Dual(ARMv7) → Special Order**
	DRAM	1 GB Mobile DRAM (Elpida)
	Flash	**16GB storage (12 GB available)**
	Sensor	**MEMS : 3 axis gyroscope** **3 axis accelerometer** **3 axis magnetometer (compass)**
	Wireless Communication	**Bluetooth, Wi-Fi** **Bone conduction transducer**
Camera	***5-megapixel***	***capable of 720p video recording***
Charger		Included Micro USB cable and charger
Battery		Single-cell Li-Polymer Battery at the end flexprint PCB(2.1Wh)

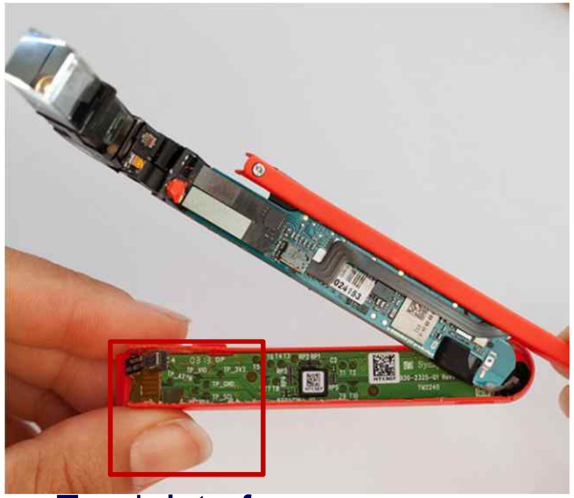
1-2. Informative Device – Google Glass

○ Google Glass Teardown

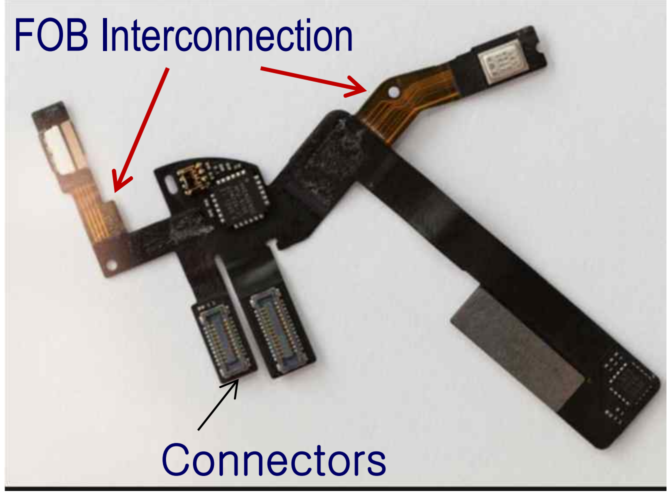
Main Board(Flash / DRAM /BT / Wifi)



Sub Board



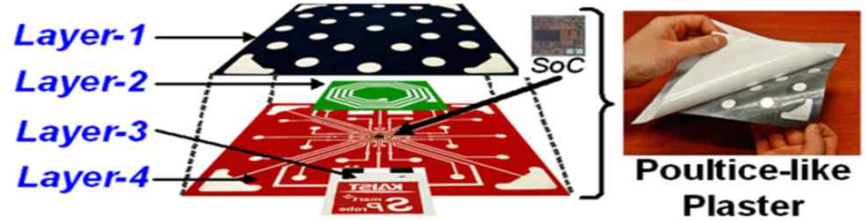
Touch Interface

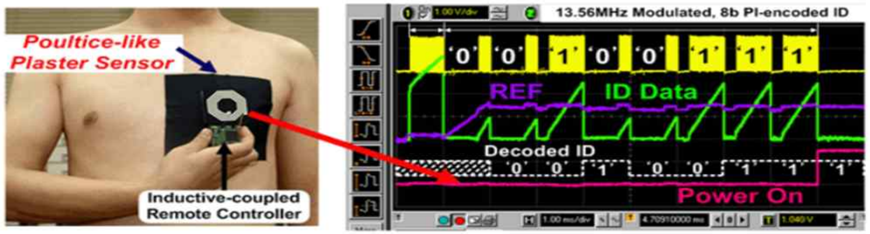


Rigid PCB, FPC, solder SMT, Connector based interconnection

1-3. Healthcare & Medical – Wearable sensors

○ Advanced Wearable Sensors





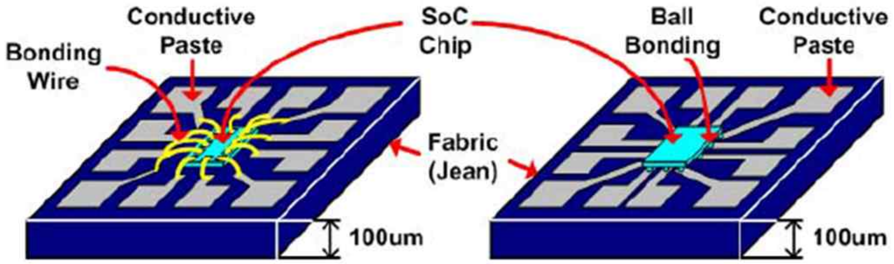


Fig. 5. Silicon-on-Clothes: direct integration of silicon onto P-FCB

SOC(Silicon on Clothes) sensor, (Hoi-Jun Yoo, KAIST)

Interconnection is challenging!

Mechanical Contact

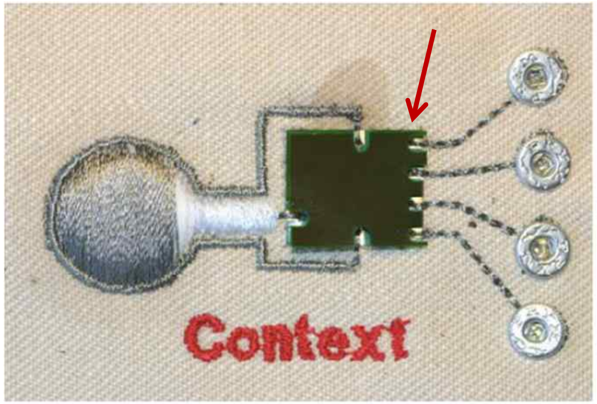
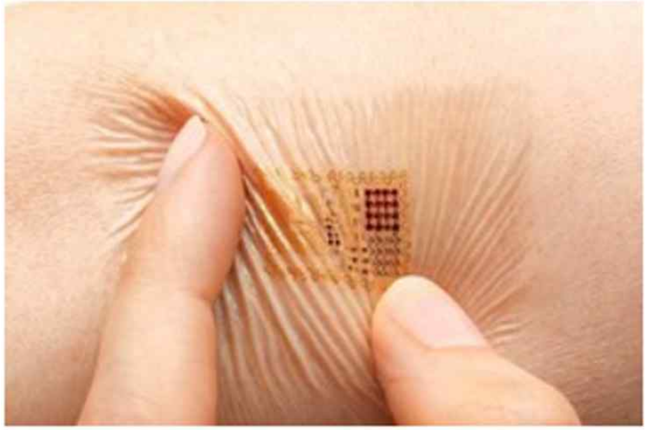


Fig. 9 Embroidered Sensor with interconnections to the electronic module and snap fasteners as interface to the computer

Fabric Wire interconnection(IZM 2013)



MC10

Flexible electronics from MC10 on a person's arm.

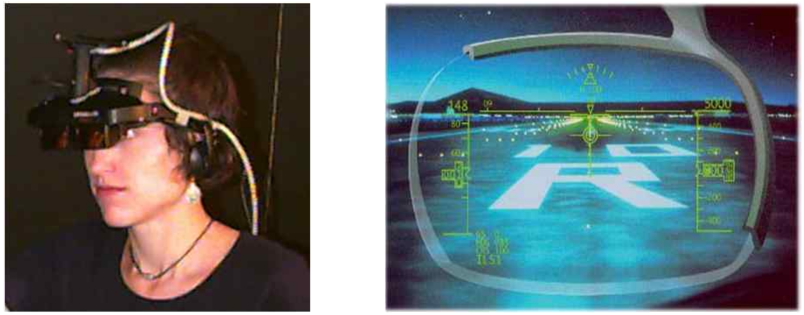
* Source : ETRI (바이오의료 IT융합연구부, 2013.07)

1-4. Industrial and Military

4. Industrial and military

- Application : Hand worn terminals, Augmented reality heat-sets etc.

Hand worn terminals
(WT41N0) Motorola

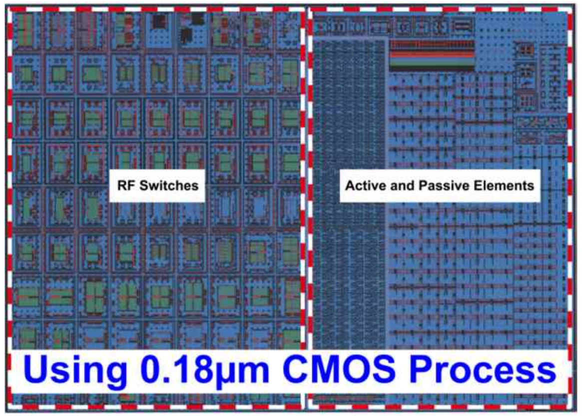


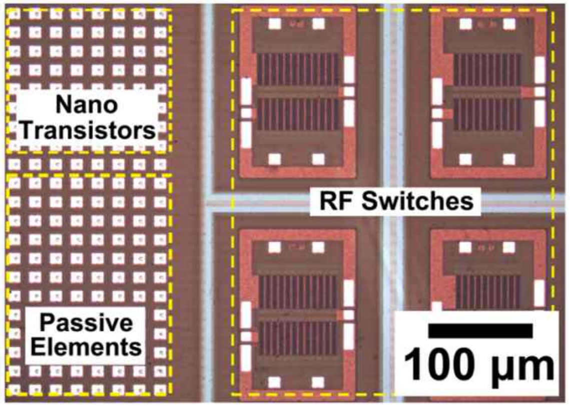
Head Up Guidance System (HGS)
(Flight Dynamics Inc.)

Flexible/Wearable Electronics 4 Core HW Technologies

1. Flexible LSI Devices
2. Flexible Batteries
3. Flexible Displays
4. **Flexible Packages & Assembly**
   - **Flexible Interconnect**
     - **Connector-based : Not good for flexibility**
     - **Solder-based : Not good for flexibility**
     - **ACF-based**
   - **Flexible IC Packages – ACF COF/CIF**
   - **Flexible Connectors – ACF FOB /FOF**

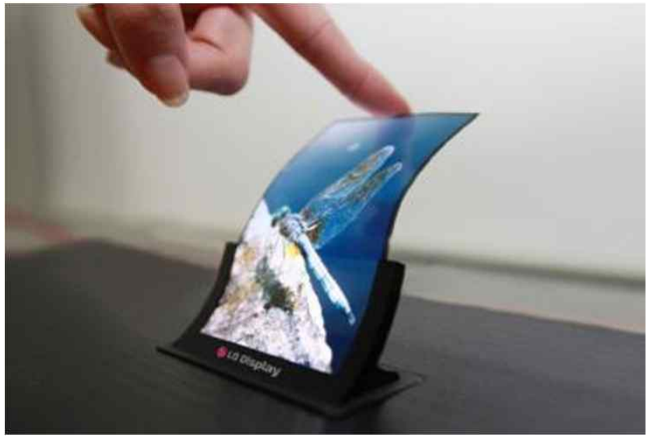
1. Flexible LSI Device





ACS Nano, 7(5), 4545, 2013

2. Flexible Display - OLED

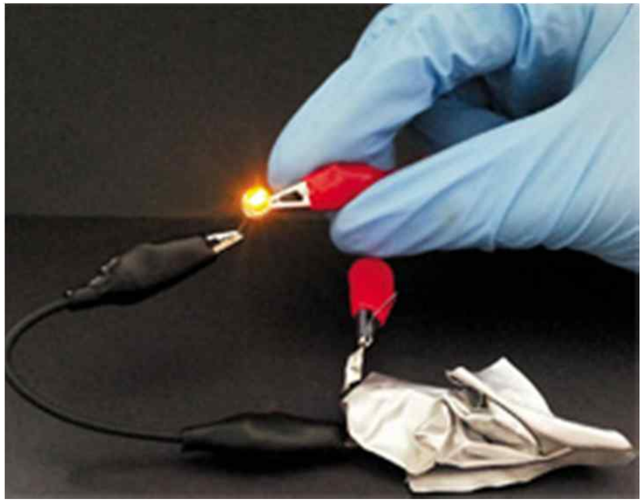


LG Display's Flexible Display

LG's G Flex Smarphones

Samsung's Curved Smartphones
using OLED on
Polymer films

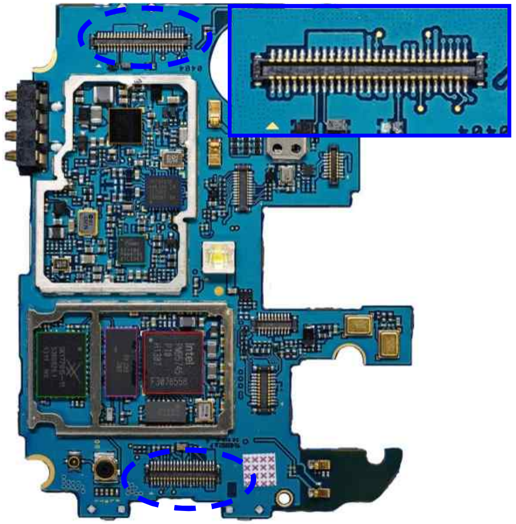
3. Flexible Battery



Anisotropic Conductive Films (ACFs) for flexible electronic packaging

- **General 3 electrical connection methods**

1) Pressure interconnection

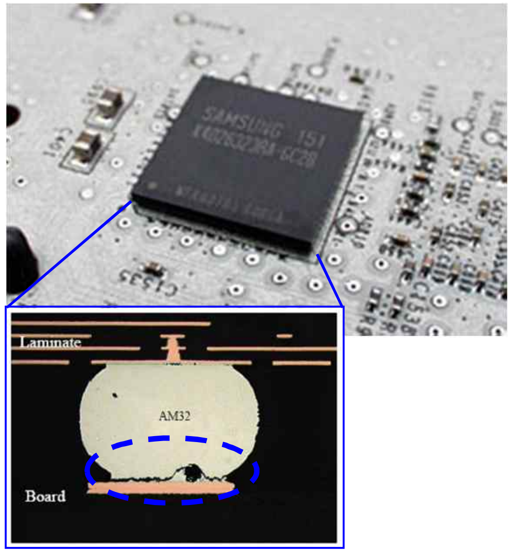


Source) Samsung Galaxy S4

No flexibility

2) Solder interconnection

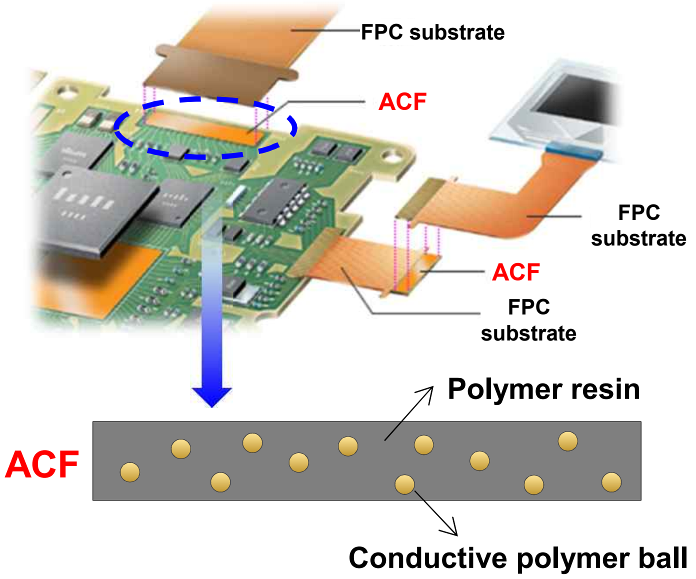
Source) Samsung



Fatigue solder crack

3) Adhesive interconnection

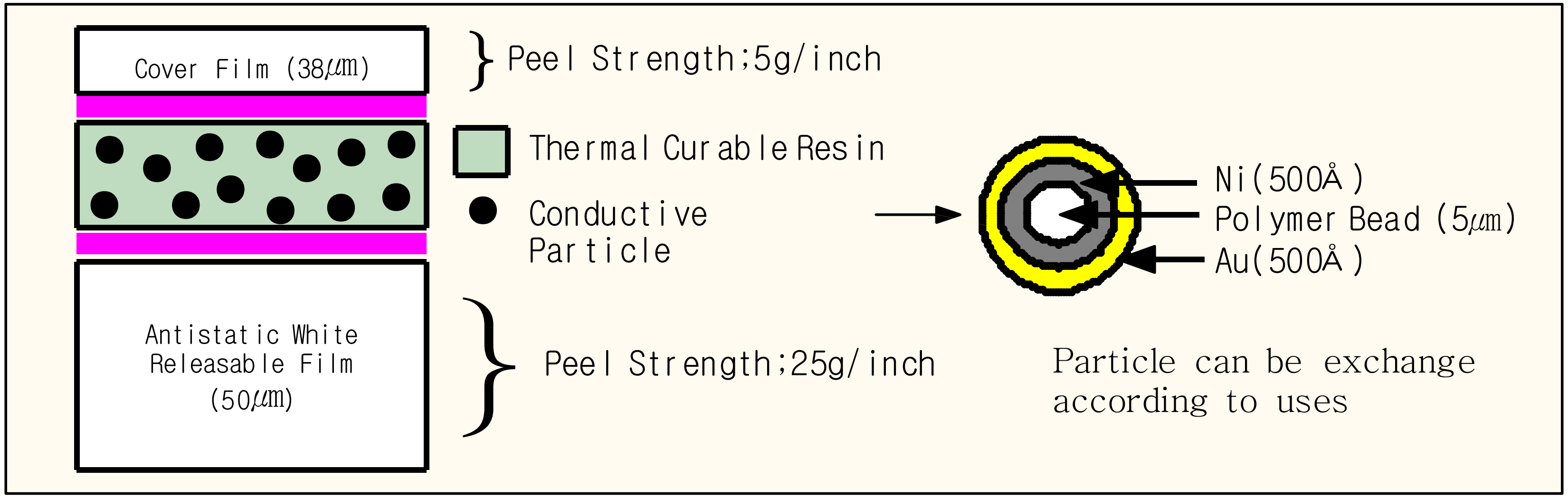
: ACF (Anisotropic conductive film)



Flexibility

ACF configuration

《CONFICURATION》



Cover Film (38㎛)

} Peel Strength;5g/inch

🟩 Thermal Curable Resin

● Conductive Particle

Ni(500Å)

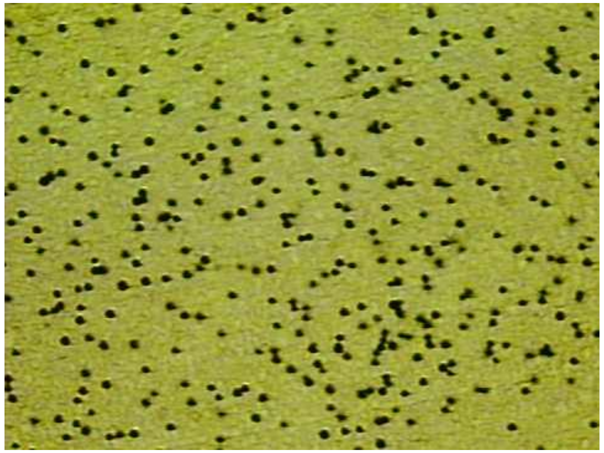
Polymer Bead (5㎛)

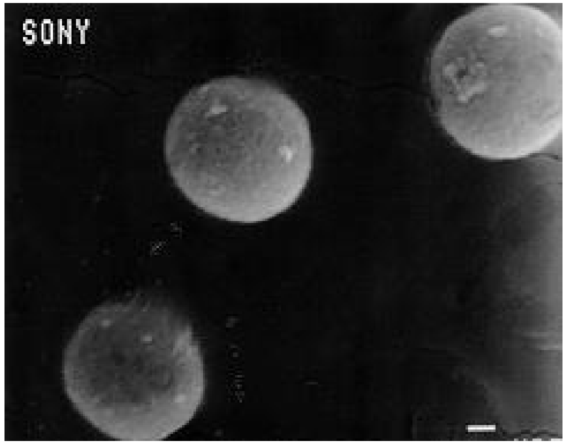
Au(500Å)

Antistatic White Releasable Film (50㎛)

} Peel Strength;25g/inch

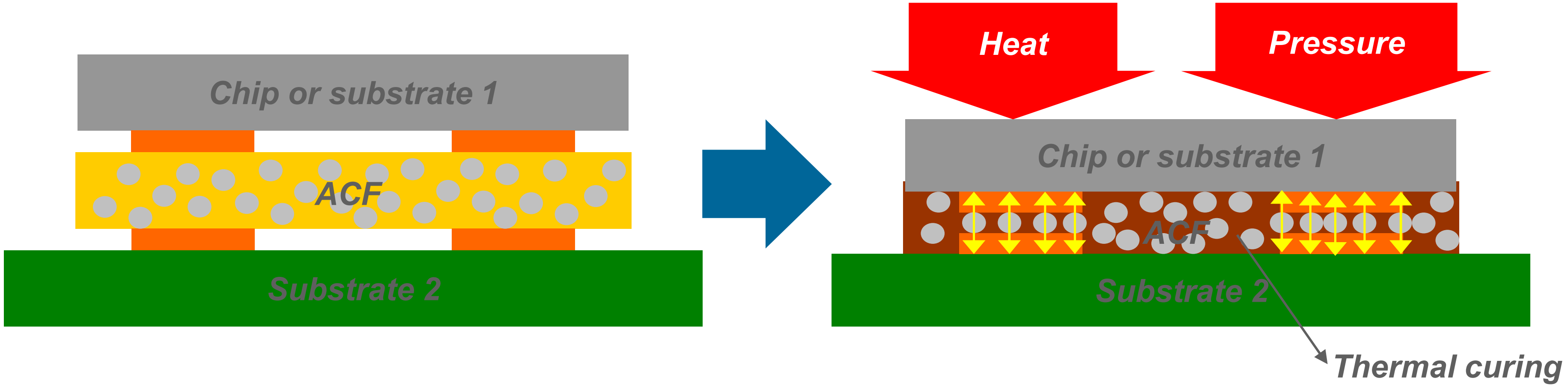
Particle can be exchange according to uses



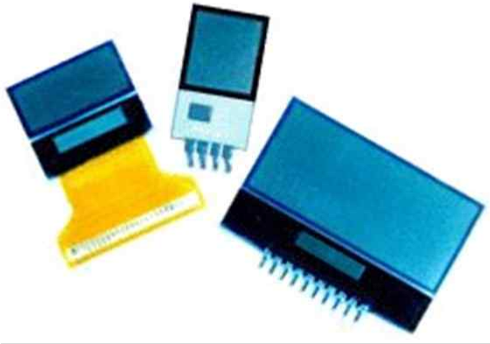


Anisotropic Conductive Films (ACFs)

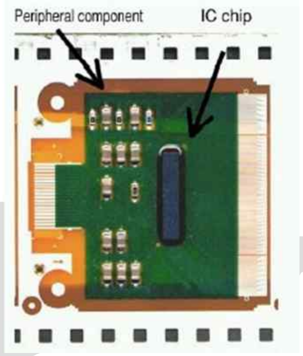
- **ACF = Thermosetting epoxy resin film + Conductive particles**



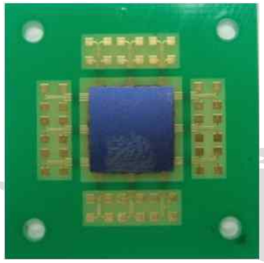
- **Applications of ACFs assembly**



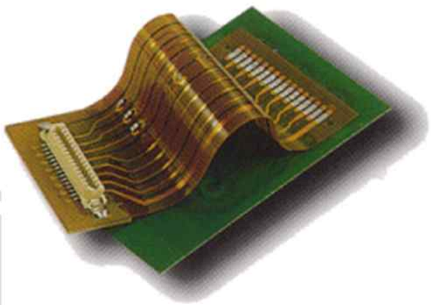
Chip-On-Glass (COG)
Chip-On-Flex (COF)
Flex-On-Glass (FOG)



Chip-On-Flex (COF)



Chip-On-Board



Flex-On-Board (FOB)

Issues on ACF flexible package structure for wearable electronics

1. **Flexible IC Package geometry design**
2. **Optimization of ACF materials**
   - ACF Polymer Resin & Conductive balls
3. **Fine pitch ACF interconnect**
   - Nanofiber ACFs (>20 um pitch)
4. **Current carrying capability**
   - Solder ball ACFs + Ultrasonic bonding
5. **Reliability**

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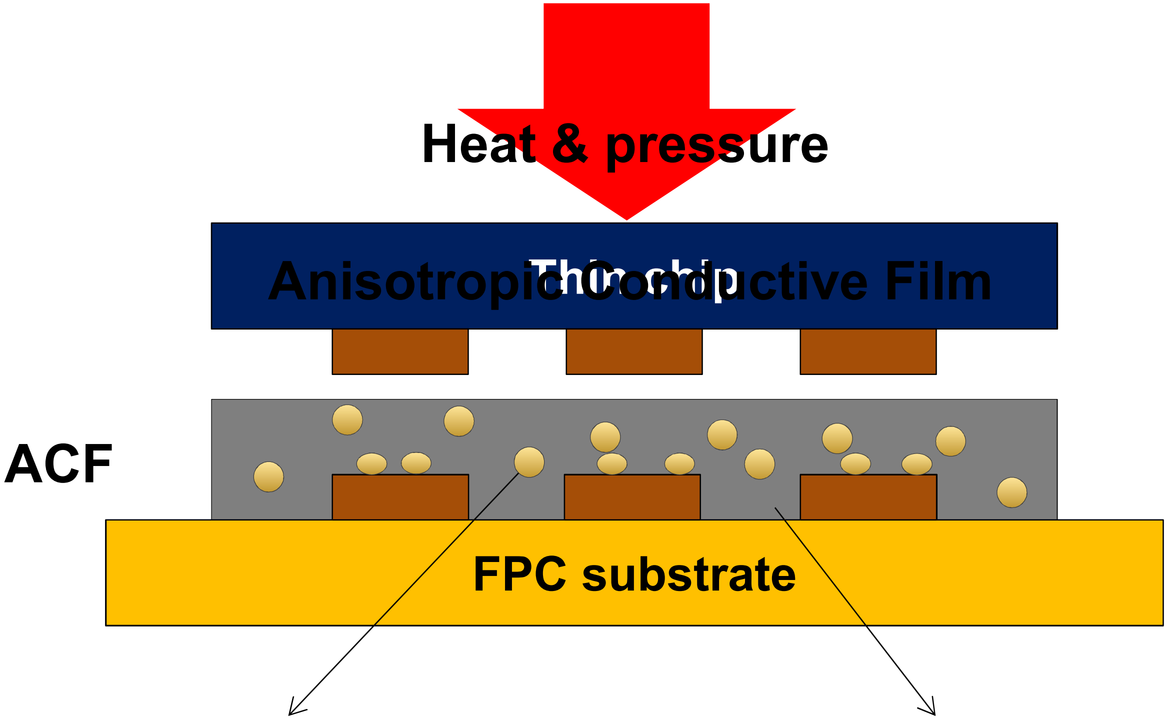
Anisotropic Conductive Films (ACFs) for flexible chip electronic packaging



Heat & pressure

Thin chip

Anisotropic Conductive Film

ACF

FPC substrate

Conductive polymer ball
(electrical conduction)

Thermosetting resin
(mechanical adhesion)

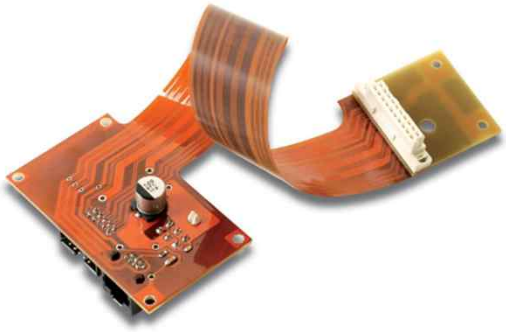
Chip-on-Flex package using ACFs is suitable for flexible package structure.

COF/CIF Packages interconnected using ACFs

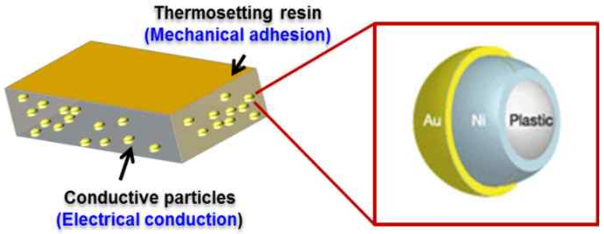
Materials & interconnection type

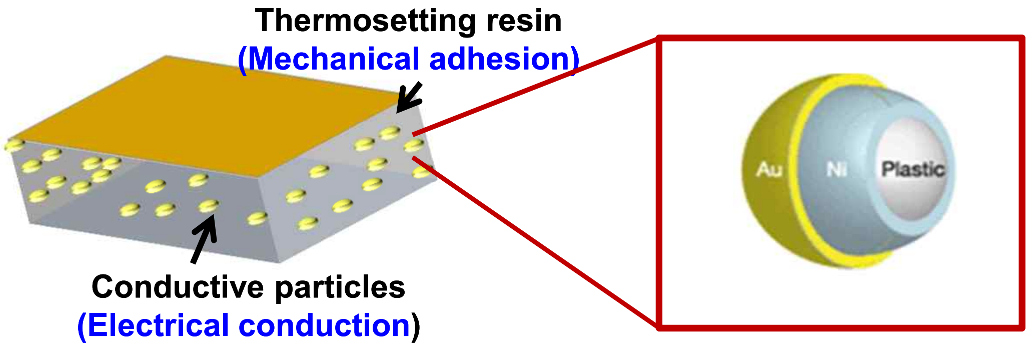
Ultra-thin Silicon chip (30um~40um)

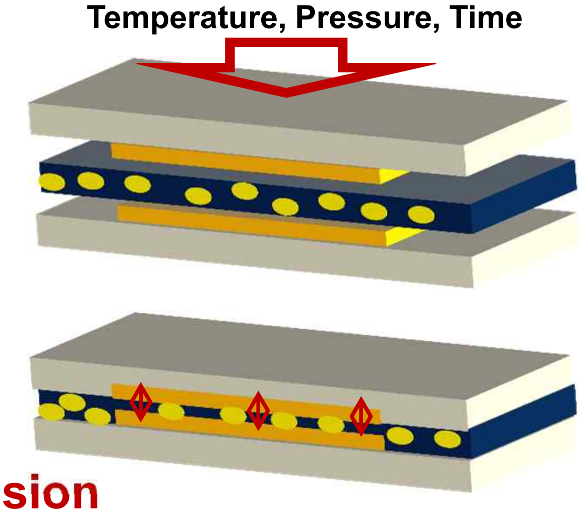
Flexible Substrate (Polyimide Film)



Flexible Interconnect using ACF



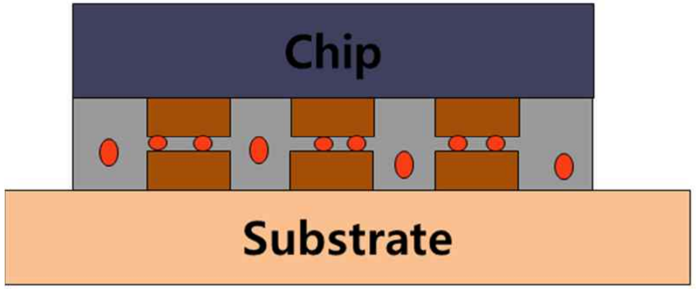




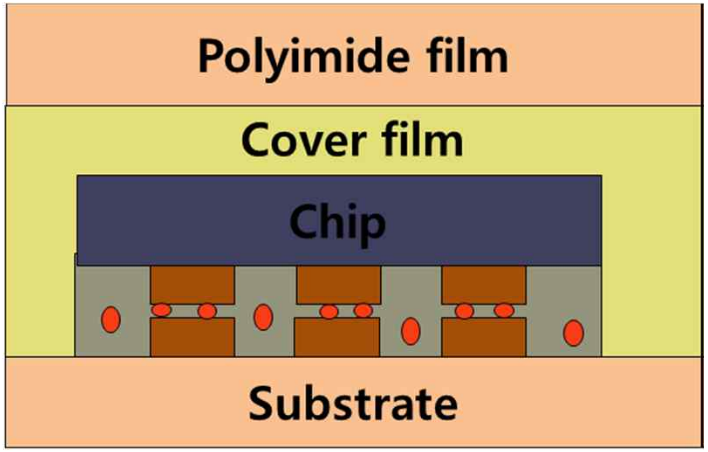
Conductivity, Insulation, Adhesion

1. Flexible IC Package geometry design:

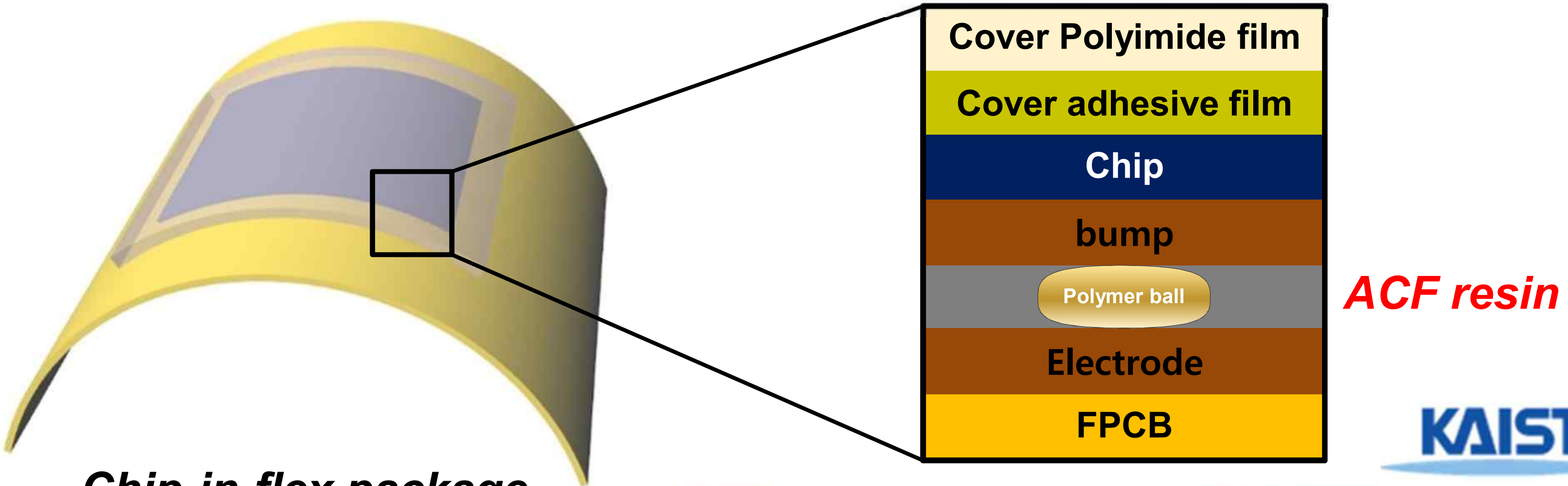
COF(Chip-on-Flex)/CIF(Chip-in-Flex) package using ACFs



COF(Chip On Flex)



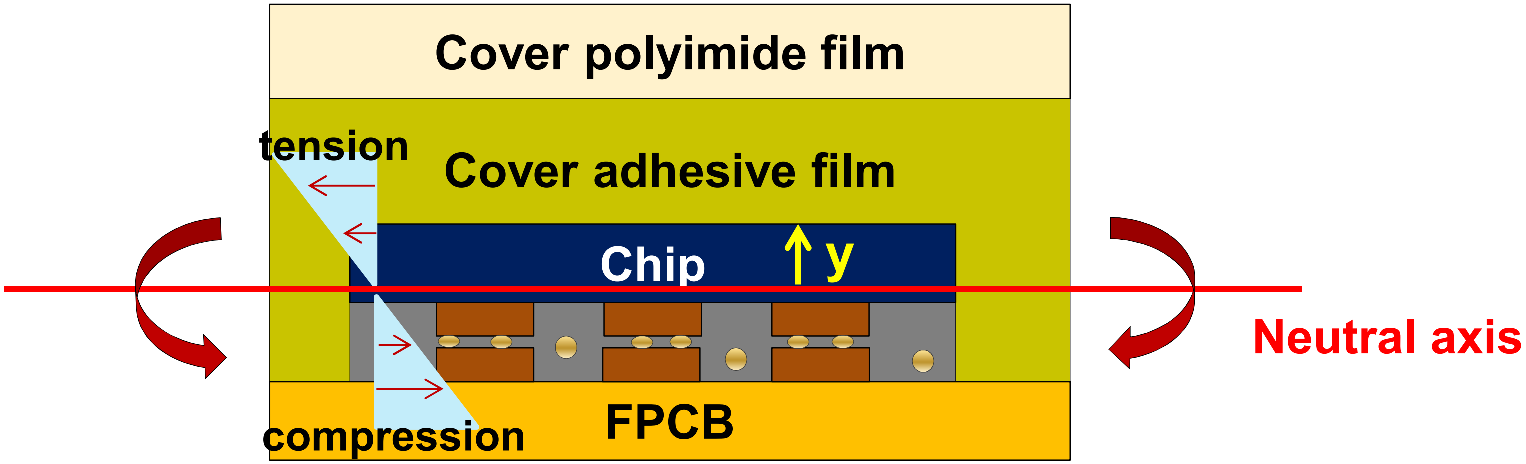
CIF(Chip In Flex)



Chip-in-flex package

Location of the Neutral axis & the Maximum Tensile Stress depending on Package Structure & Package Geometry

Chip-in-Flex



Neutral axis : axis with no strain or no stress

<Position of Neutral axis>

$$y_N = \frac{\sum_i E_i \int_{A_i} y' dA}{\sum_i E_i A_i} = \frac{\sum_i E_i \bar{y}_i A_i}{\sum_i E_i A_i}$$

y_N = neutral axis

E = elastic modulus

$\bar{y}$ = distance from bottom

A = cross − sectional area

<Maximum tensile stress on the chip surface>

$$\sigma = \frac{E_{si} \times \boxed{y}}{\rho}$$

σ = bending stress

E = elastic modulus

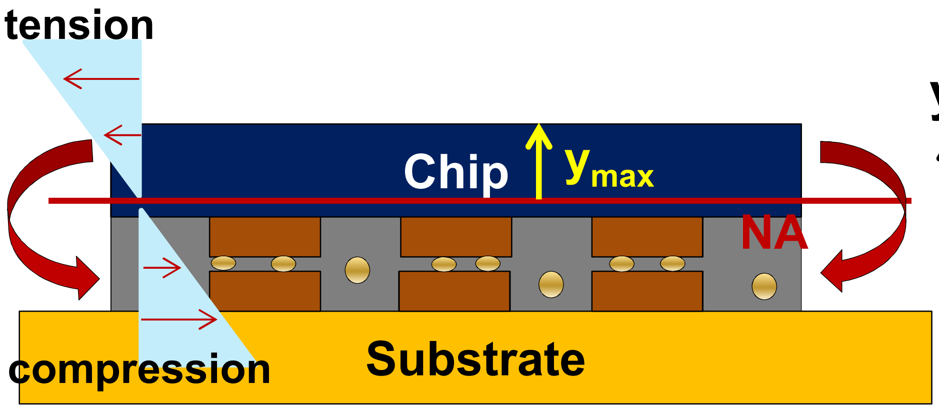
$\boxed{y = \text{distance from neutral axis}}$

ρ = bending radius

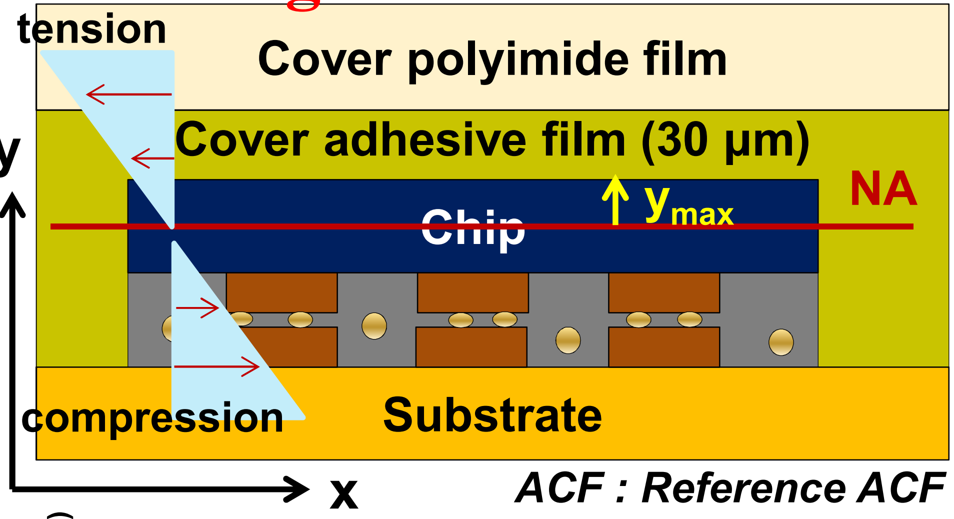
The location of the Maximum tensile stress on the chip surface depending on COF/CIF packages

Concave Bending

COF



CIF

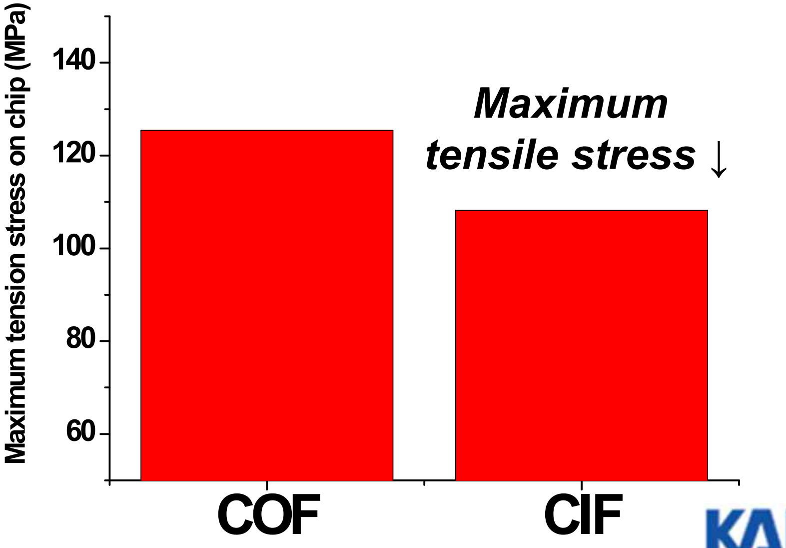


ACF : Reference ACF

<Maximum tensile stress on the chip surface>

$$\sigma = \frac{E_{si} \times \boxed{y}}{\rho}$$

σ = *bending stress*
E = *elastic modulus*
y = *distance from neutral axis*
ρ = *bending radius*



@ concave bending radius : 5mm

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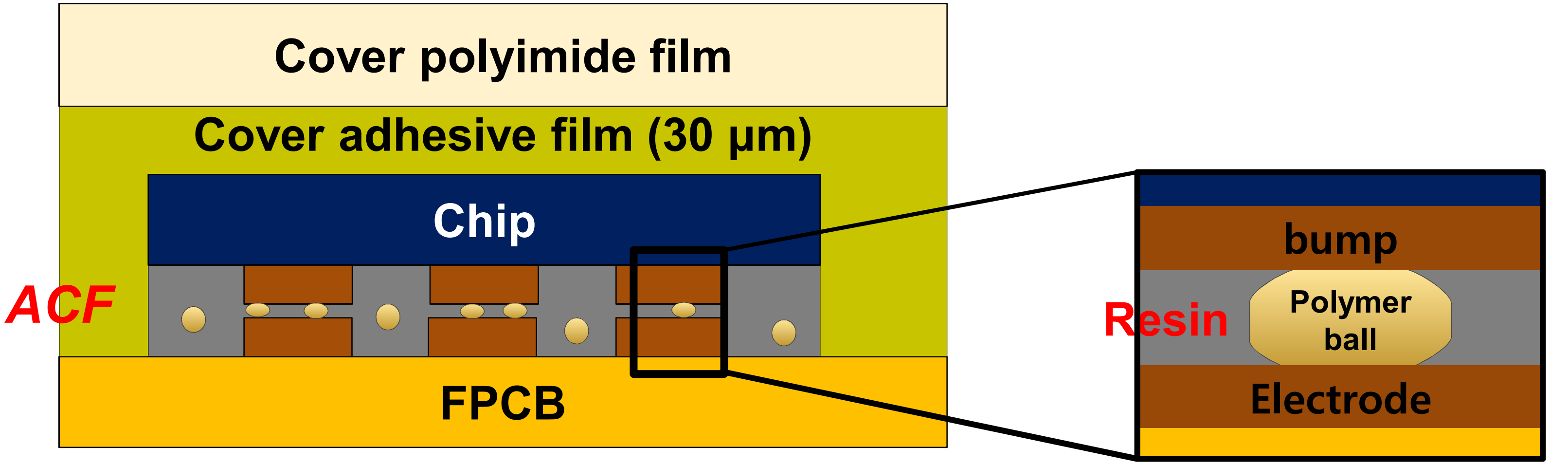
5. **Reliability**

2. Optimization of ACF materials :
ACF polymer resin property on the flexibility of CIF PKG

Evaluation of CIF package bending reliability depending on

ACF polymer resin property



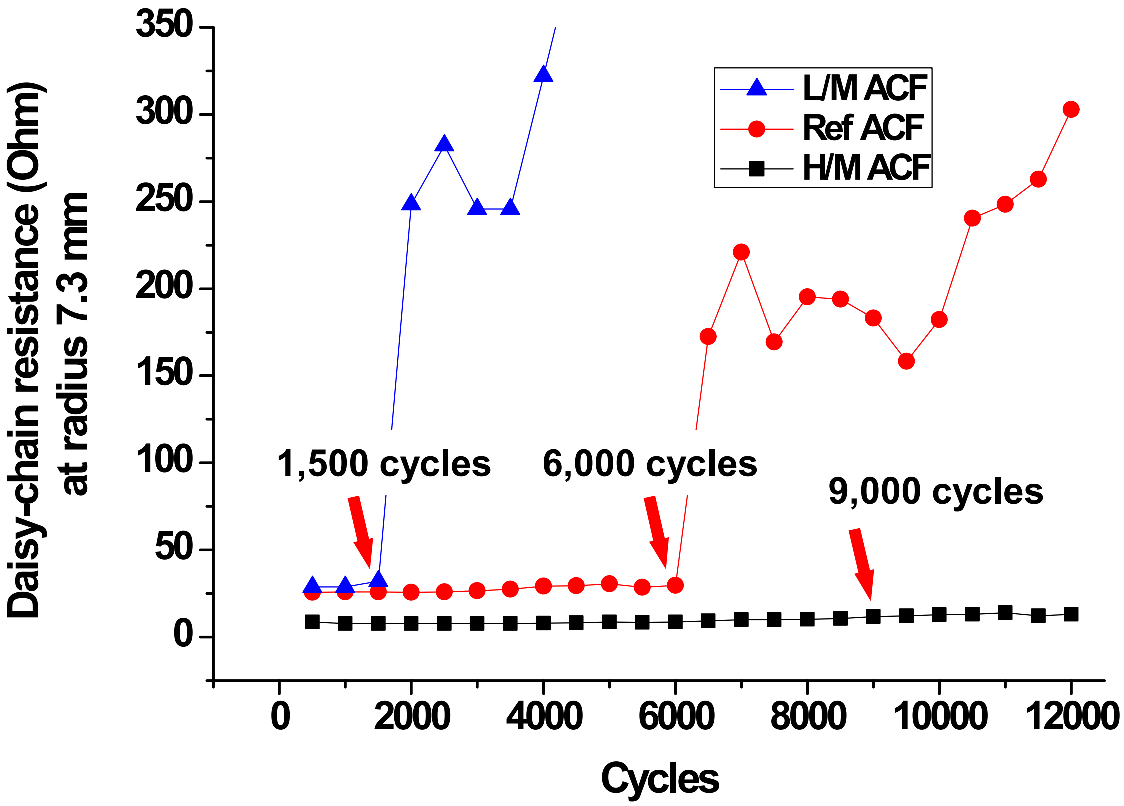
CIF packages ***ACF resin property***

ACF	Modulus
Low modulus ACF	0.9 GPa
Reference ACF	1.57 GPa
High modulus ACF	1.82 GPa

Effects of ACF resin properties on the flexibility of CIF PKG under dynamic bending test

ACF	Low modulus ACF	Reference ACF	High modulus ACF
Modulus	0.9 GPa	1.57 GPa	1.82 GPa

***In-situ* dynamic bending test**
160k cycles (@ R7.3 mm)



As modulus of ACF increased, dynamic bending life increased.

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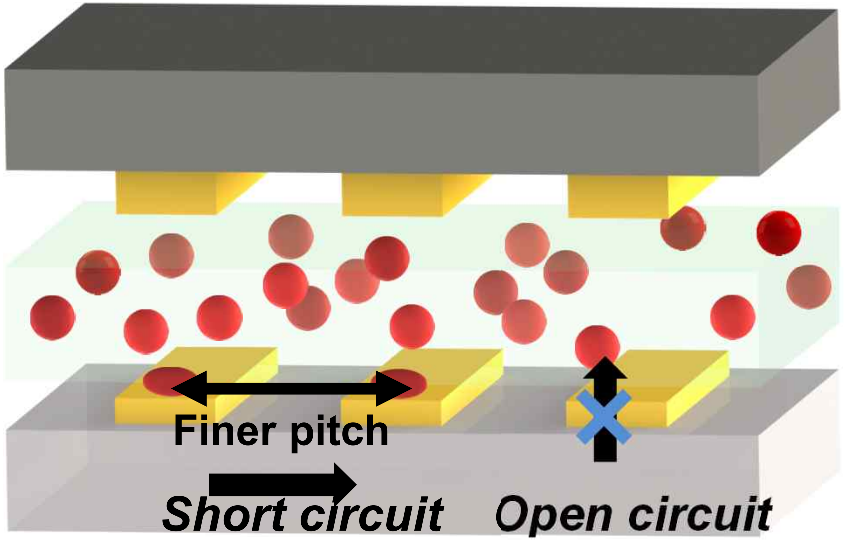
Samsung unveils its entire UHD TV lineup at CES 2014, leading with a 110-inch monster.

UHD: 4K Technology

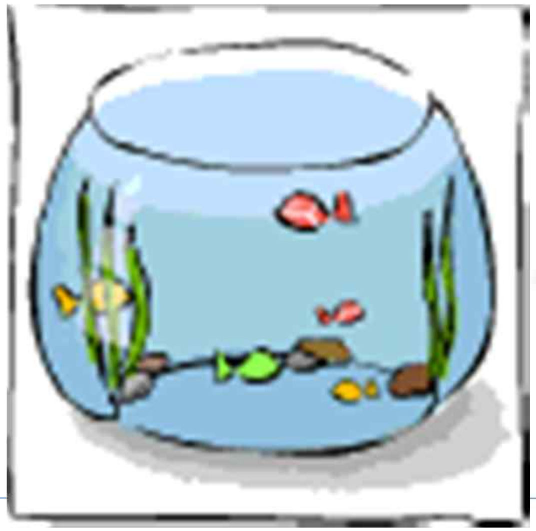
UHD(Ultra High Definition) & QHD(Quad High Definition) LCD panel requires ultra fine pitch I/O interconnection!

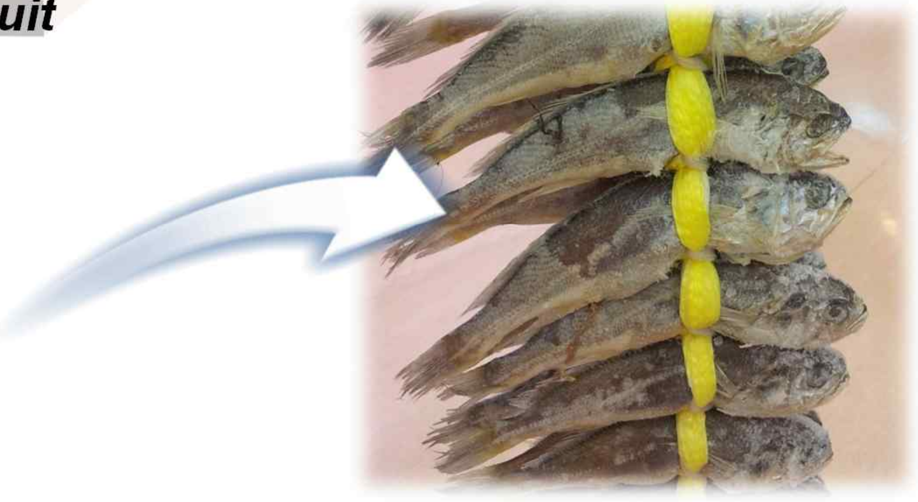
Issues for Fine Pitch Interconnection Using ACFs

❐ *Unstable electrical performances on fine pitches*



- **Short circuit:** agglomerated CPs
  → electrical conduction in X-axes
- **Open circuit / high resistance:**
  Non-captured or small # of CPs in Z-axis
  → higher joint resistance
  → poor reliability

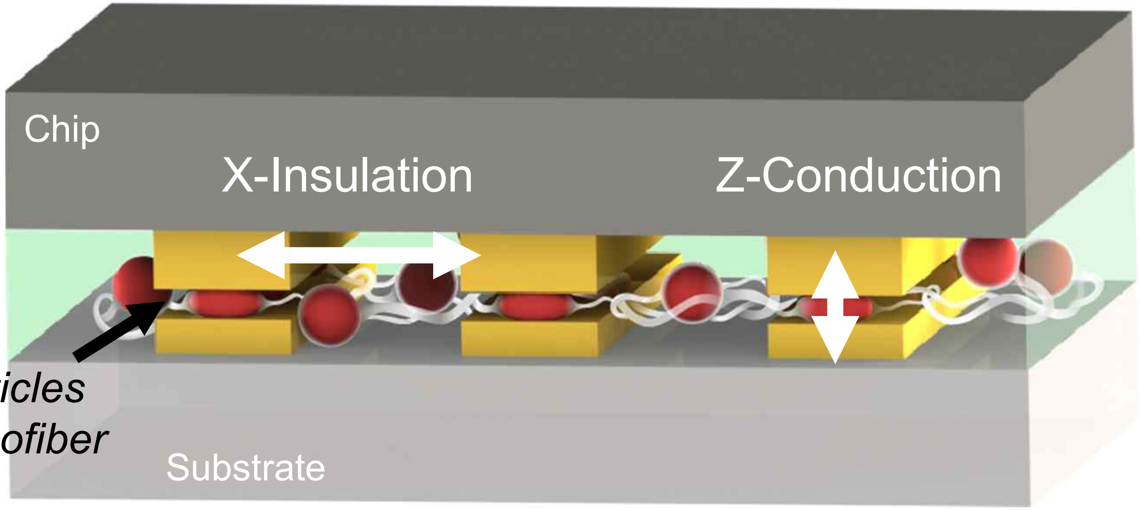




"Gulbi" at Korea

Why Nanofiber ACFs?

Nanofiber ACF



Conductive particles incorporated nanofiber
(CPIN)

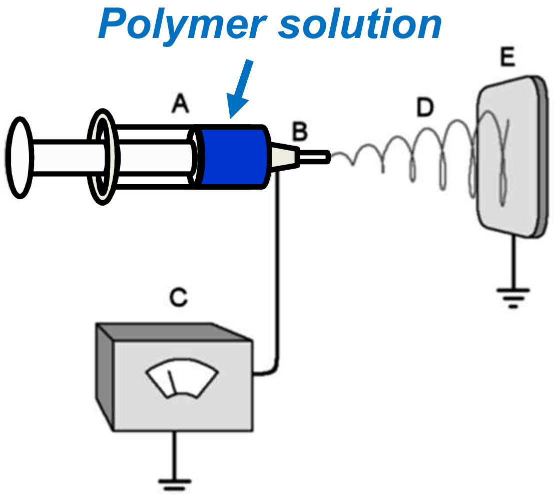
- Korea patent
  :10-1115686 (issued)
  :10-1146351 (issued)
  :10-1160971 (issued)
  :10-2011-0022041
- PCT patent pending
  :PCT/KR2010/006623
- USA patent pending
  :13/075,147
- Japan patent pending
  :2011-072488
  :2012-532008
- China patent pending
  :201110111458.0

Suppressing CP movement
→ No short circuit & open circuit

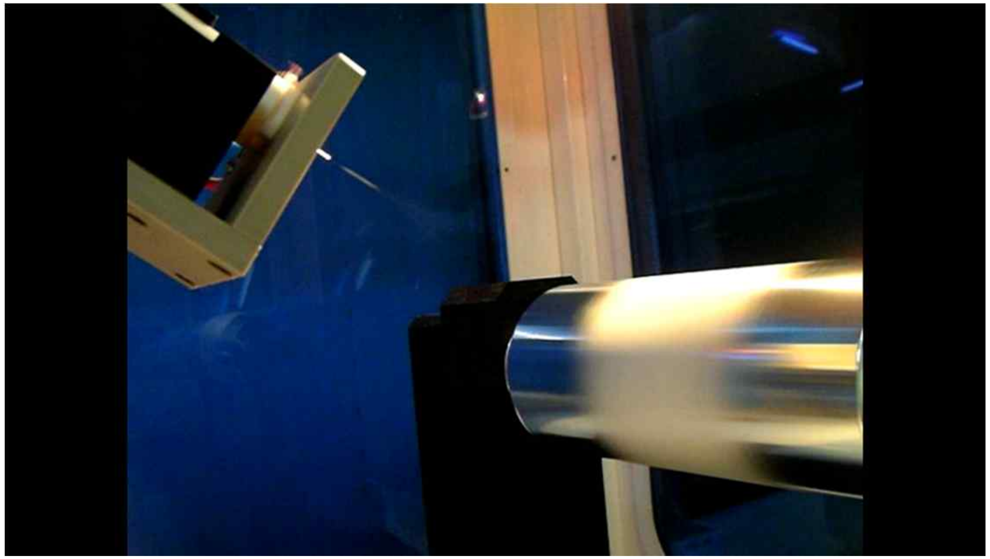
Ref) Kyoung-Lim Suk, Chang-Kyu Chung and Kyung-Wook Paik, 61st ECTC, Florida, USA, May 31-June 3, 2011.

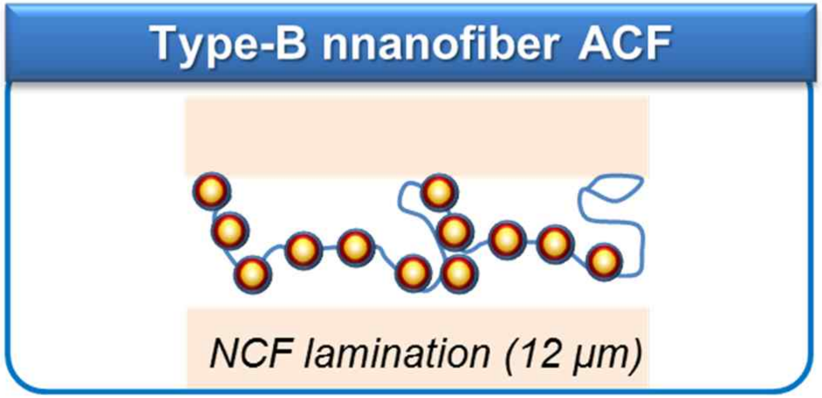
Nanofiber ACFs Fabrication

❐ *Nanofiber formation by electro-spinning*

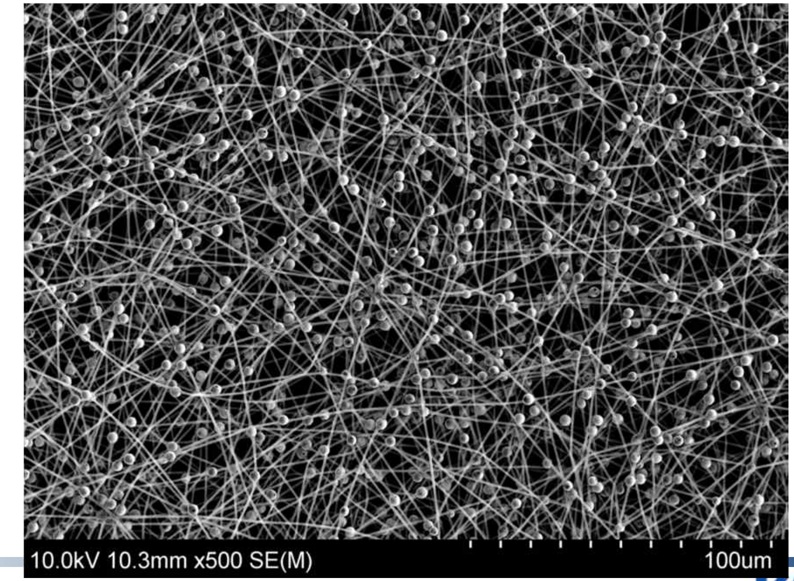


A: Syringe, **B:** Needle, **C:** High voltage power supply, **D:** Nanofibers, **E:** Collector units



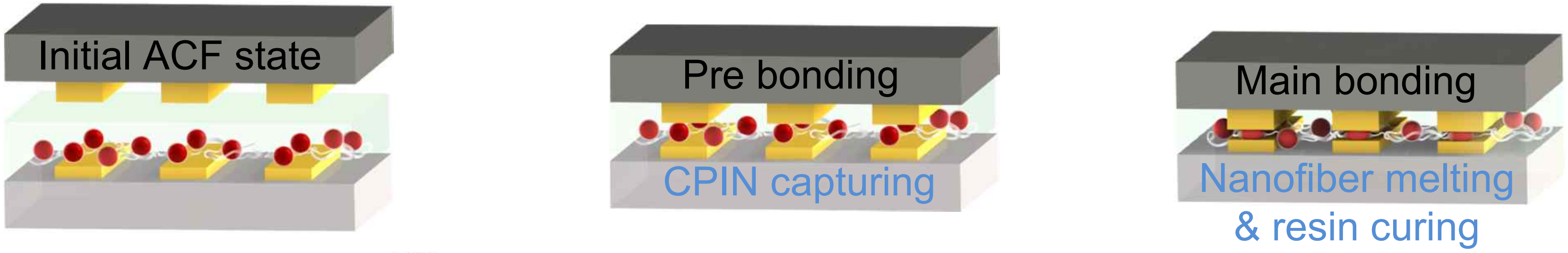


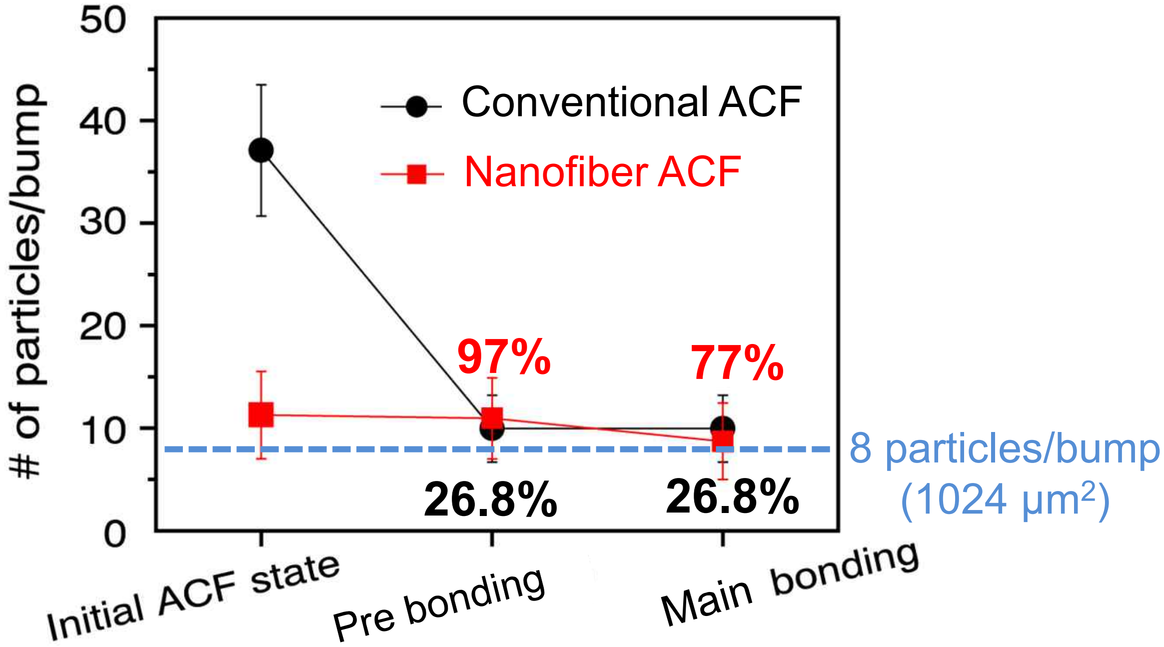
- NCF lamination on Conductive particle coupled nanofiber



Particle Capture Rate of Nanofiber ACFs

❒ *Conductive particle movement during the bonding process*

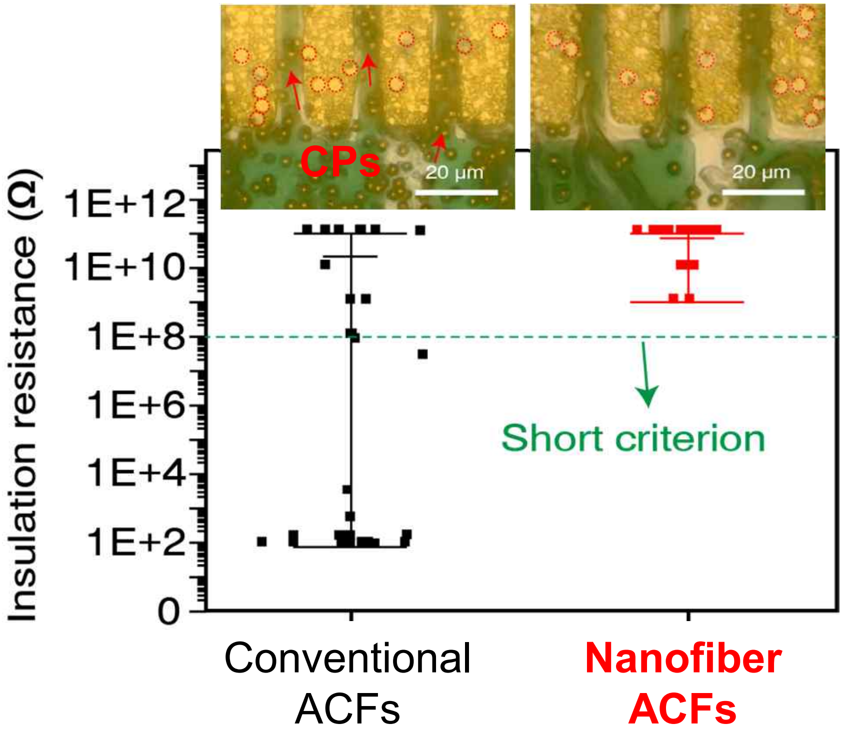




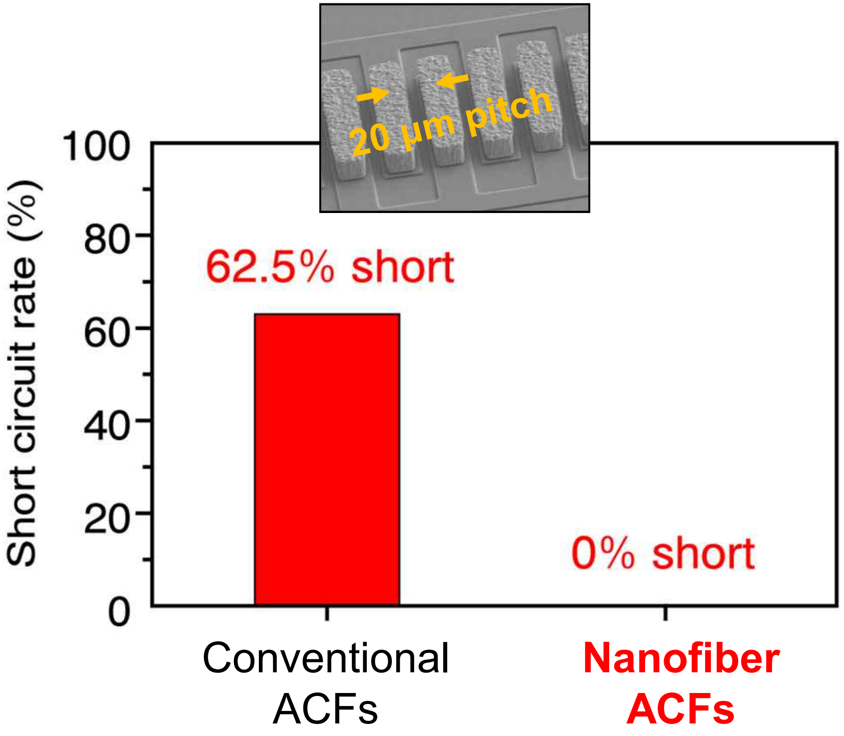
❖ **Nanofiber ACF suppressed the particle movement** compared to the conventional ACF during resin flow.

Short Circuit Rate of Nanofiber ACFs

❒ *X-axis insulation resistance*



❒ *Short circuit rate at 20 μm pitch*



❖ Nanofiber ACF successfully ***suppressed the conducive particle movement*** resulting in ***zero short circuit rate at 20 μm pitch.***

Issues on ACF flexible package structure for wearable electronics

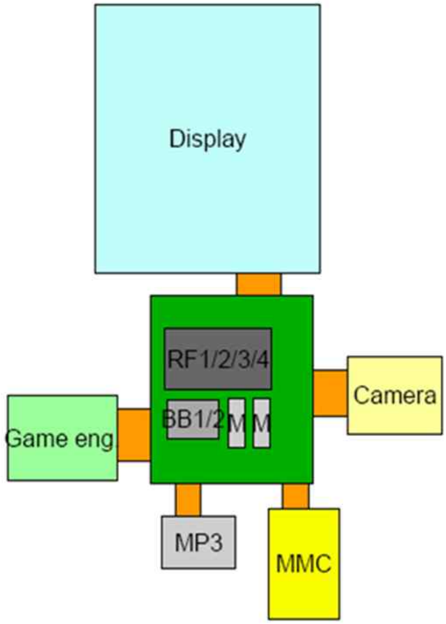
1. **Flexible IC Package geometry design**
2. **Optimization of ACF materials**
   - ACF Polymer Resin & Conductive balls
3. **Fine pitch ACF interconnect**
   - Nanofiber ACFs (>20 um pitch)
4. ***Current carrying capability***
   - Solder ball ACFs + Ultrasonic bonding
5. ***Reliability***

Recent issues in mobile device packages - Modulization

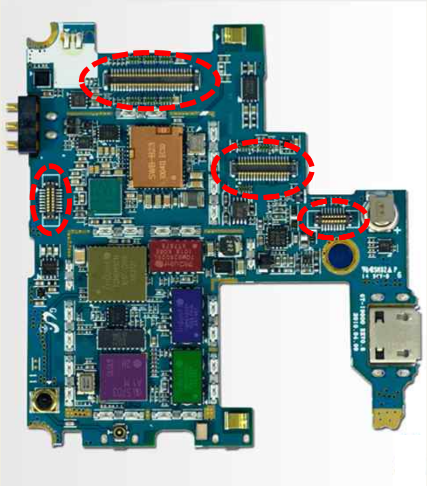
- **Current trends in mobile devices**

Source : Nokia

1. **High performance**
2. **Multi-functionalization**
3. **Miniaturization**



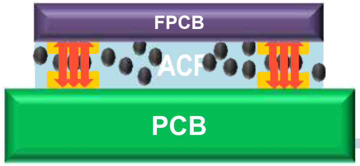
Conventional Socket-type connectors

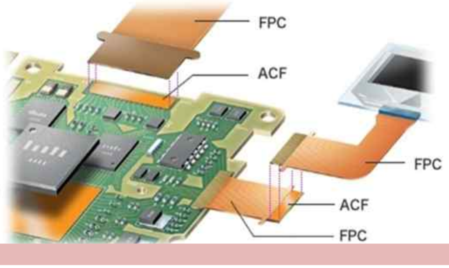


✓ **Disadvantages**

- Large volume & height
- Large pitch size 400 um pitch

FOB(Flex-on-Board) & FOF (Flex) assembly using ACFs

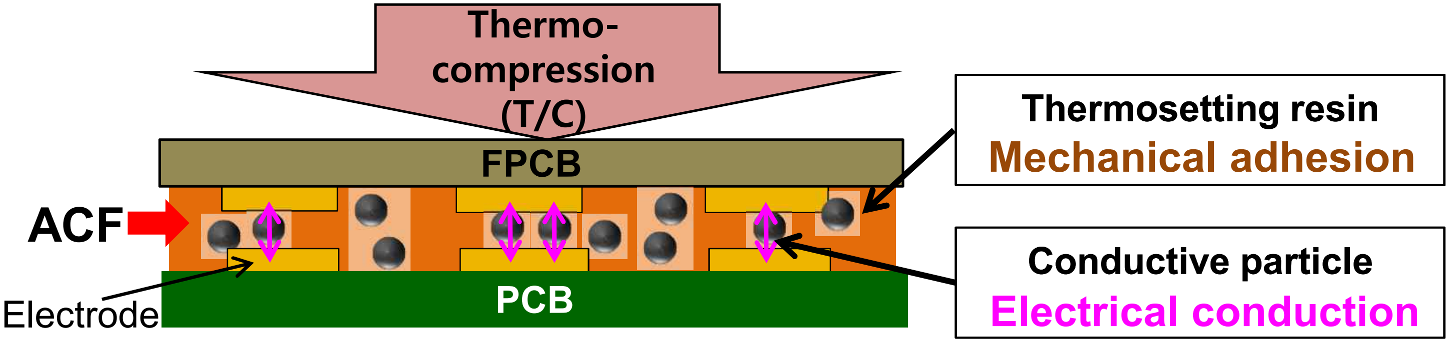




✓ **Advantages**

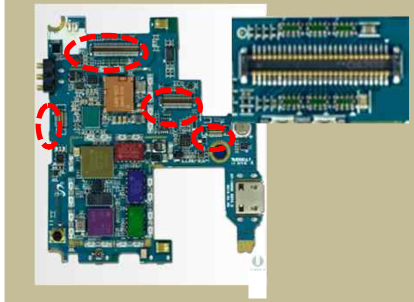
- Fine pitch capability
- Reduced package size
- Process effectiveness

Anisotropic Conductive Films (ACFs) for FOB assembly



- **ACF FOB Advantages**

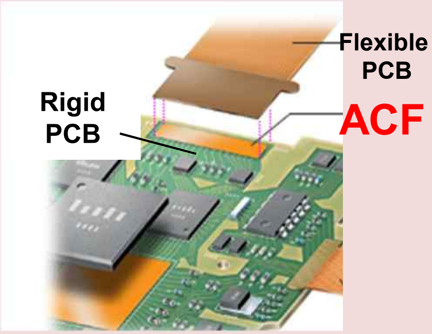
<Conventional Socket-type connector>



- *Large volume*
- *Large pitch size*

Source: Nokia

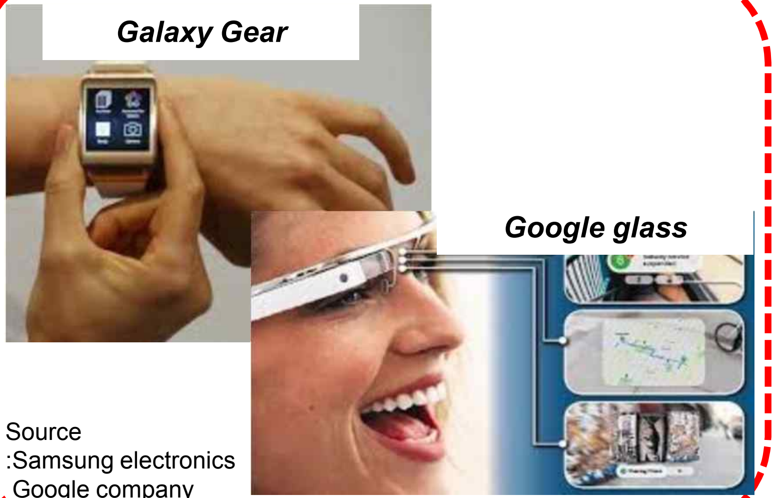
<ACF bonding>



- ***Reduced package size***
- ***Fine pitch capability***

- **ACF FOBs in wearable devices**

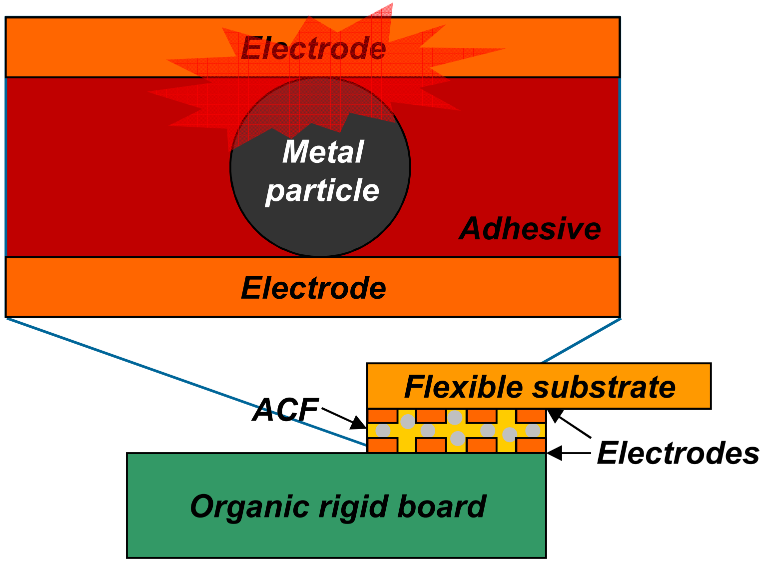
<Wearable device>



Source
:Samsung electronics
Google company

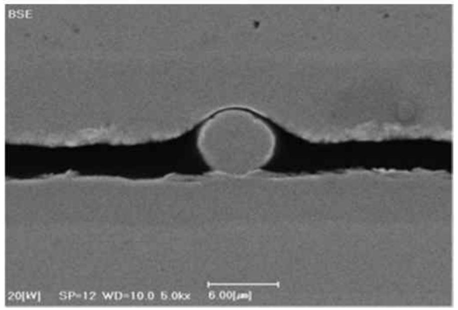
Solder ACFs for high current handling capacity

Conventional ACF

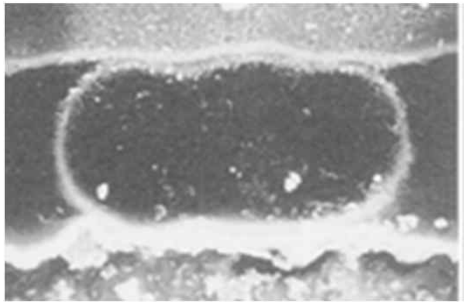


Physical point contact of metal particles

- Limitations in electrical properties and reliability



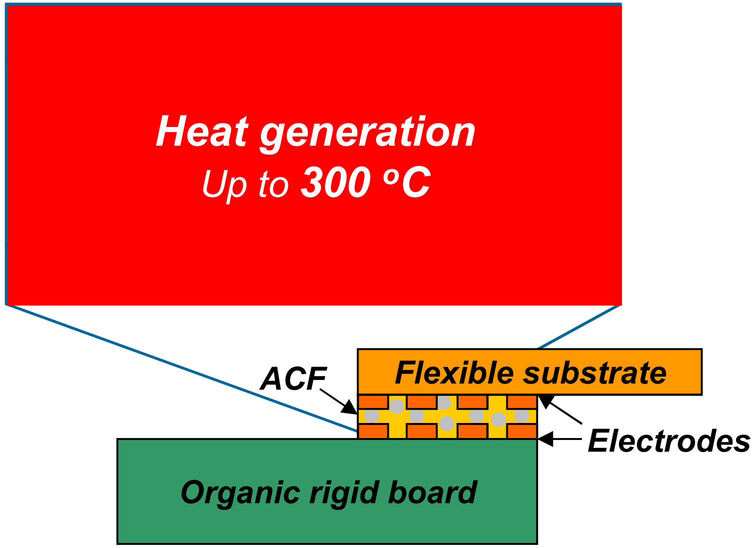
Ni ball



Metal coated polymer ball

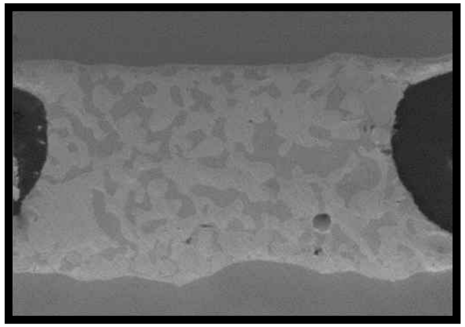
Solder ACF + U/S

Patent pending



Metallurgical bonding of solder particles

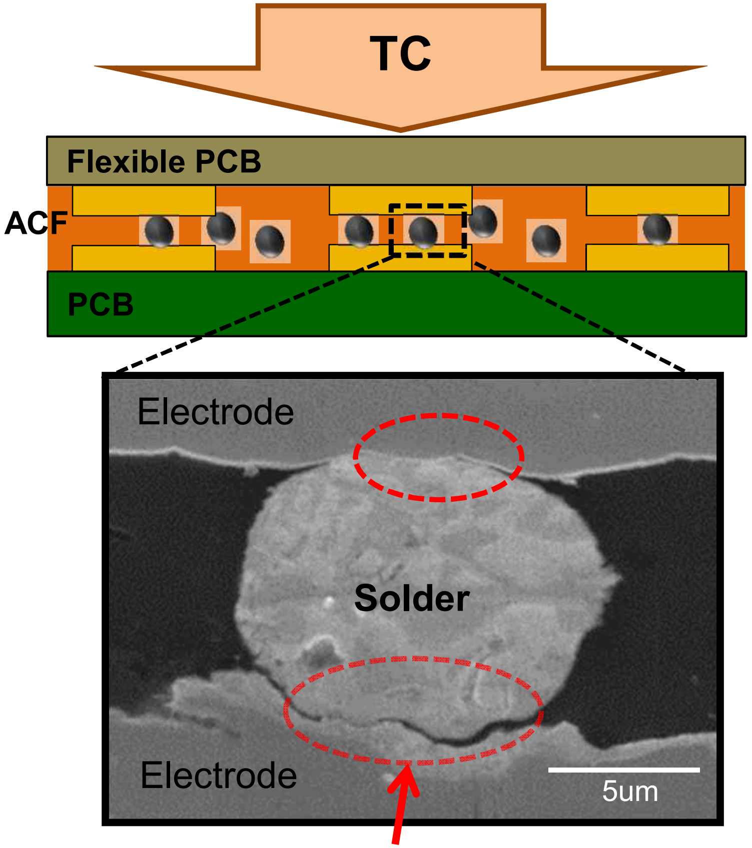
- Higher current carrying capability
- Improved reliability



Solder ball

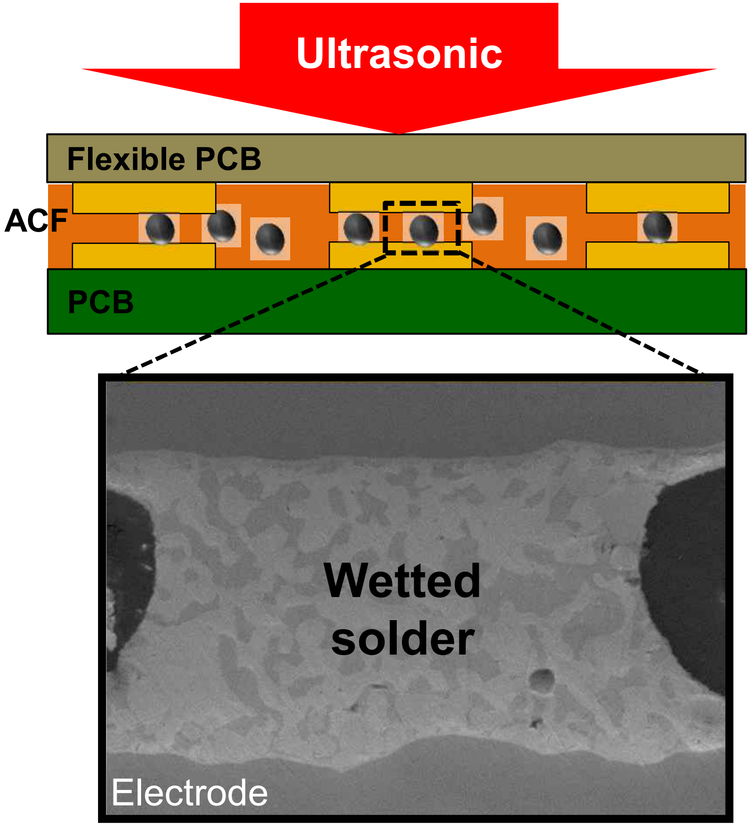
Solder particles in ACFs : Solder Oxide Layer problems – Ultrasonic Bonding

- **Thermo-compression (TC) bonding**



Partial solder wetting by remained solder oxide layer

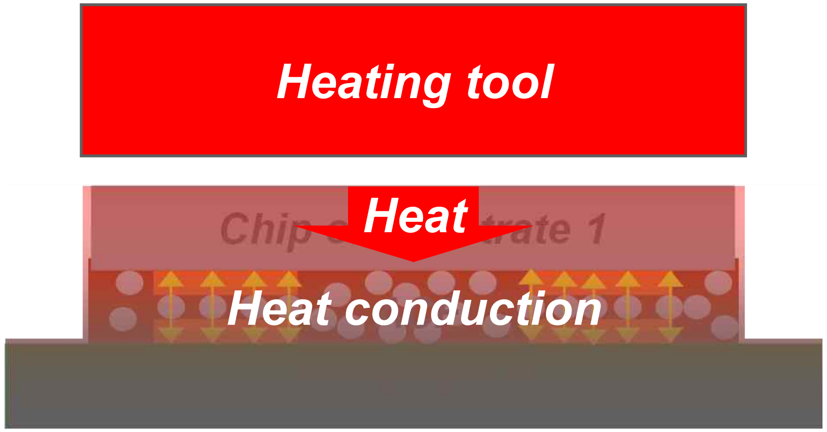
- **Ultrasonic bonding**



Excellent solder wetting by broken solder oxide layer

ACFs bonding – Thermocompression(T/C) vs. Ultrasonic(U/S)

T/C ACFs bonding

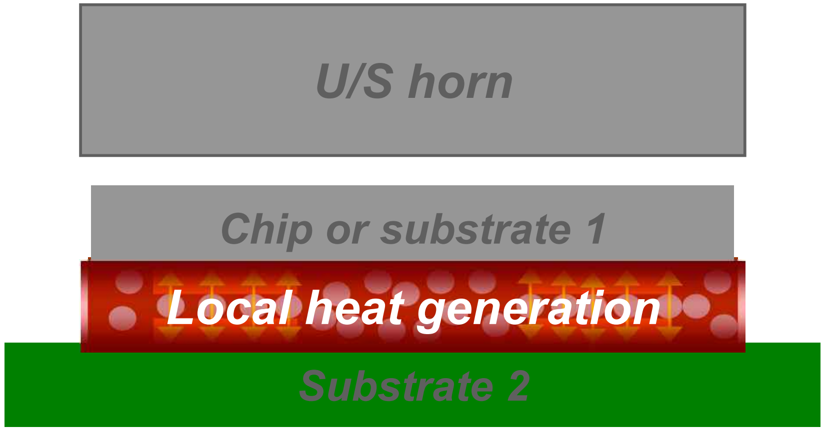


Heating tool (250 ℃~350 ℃)

→ ACF temperature (180 ℃)

- → **Thermal conduction – slow**
- → **Thermal damages**
- → **High Energy waste**

U/S ACFs bonding Patented



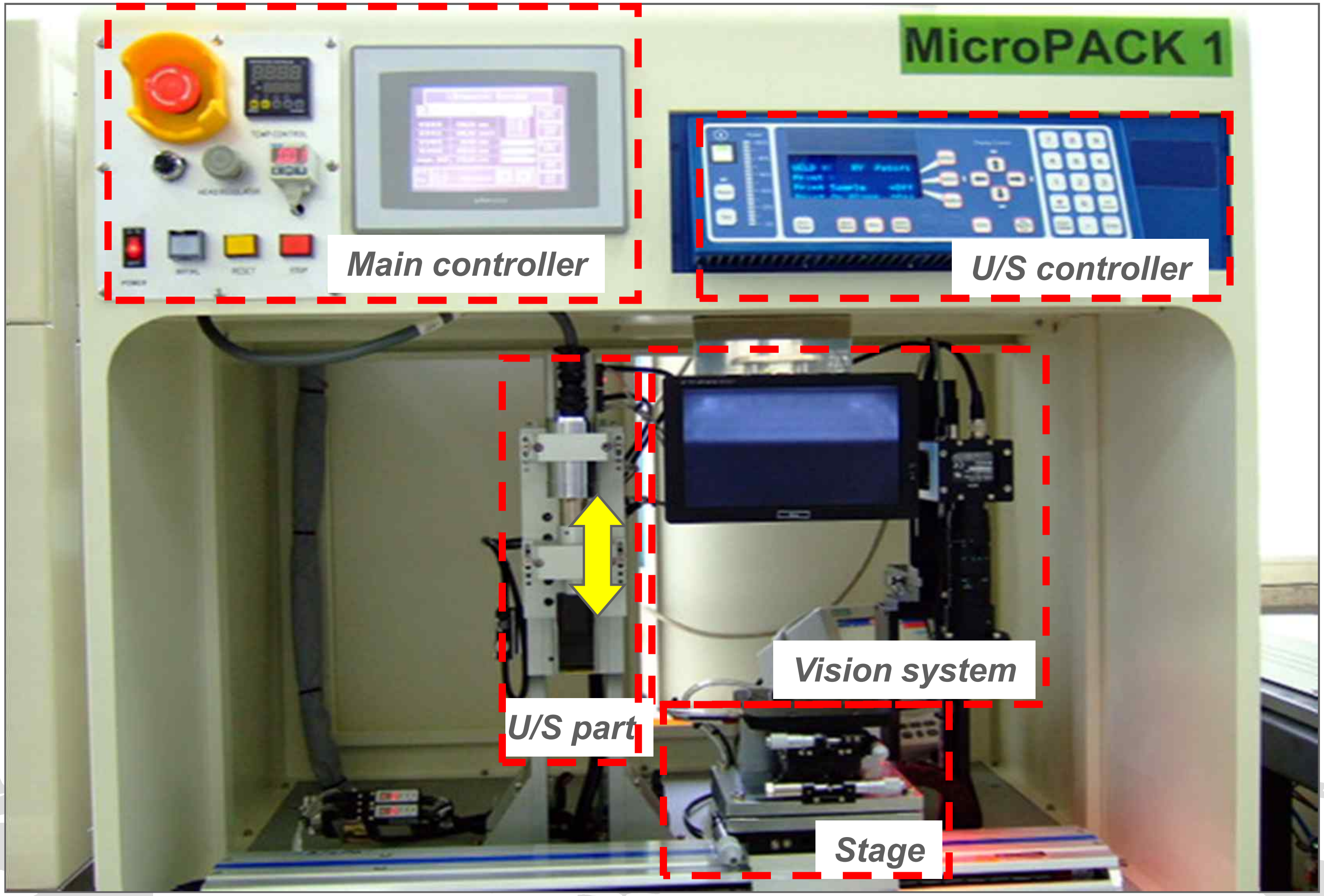
U/S horn (R.T.)

→ ACF temperature(> 250 ℃)

- → **Fast (1/2 ~ 1/3 bonding times)**
- → **No thermal damages**
- → **Energy saving (No heating, 1/10)**

The 1st Commercial U/S ACF bonding machine

MPB-U110 : 1 head, 1 stage, manual alignment



Advantages of U/S vs. T/C ACF bonding

1. Reduced Assembly Times & Cost

- **Faster ACFs bonding times** of U/S method
  - Epoxy ACFs: 3 ~ 5 sec. vs. 7 ~ 15 sec.
  - Acrylic ACFs: 1 ~ 3 sec vs. 5 ~ 7 sec.

2. No thermal damage on boards

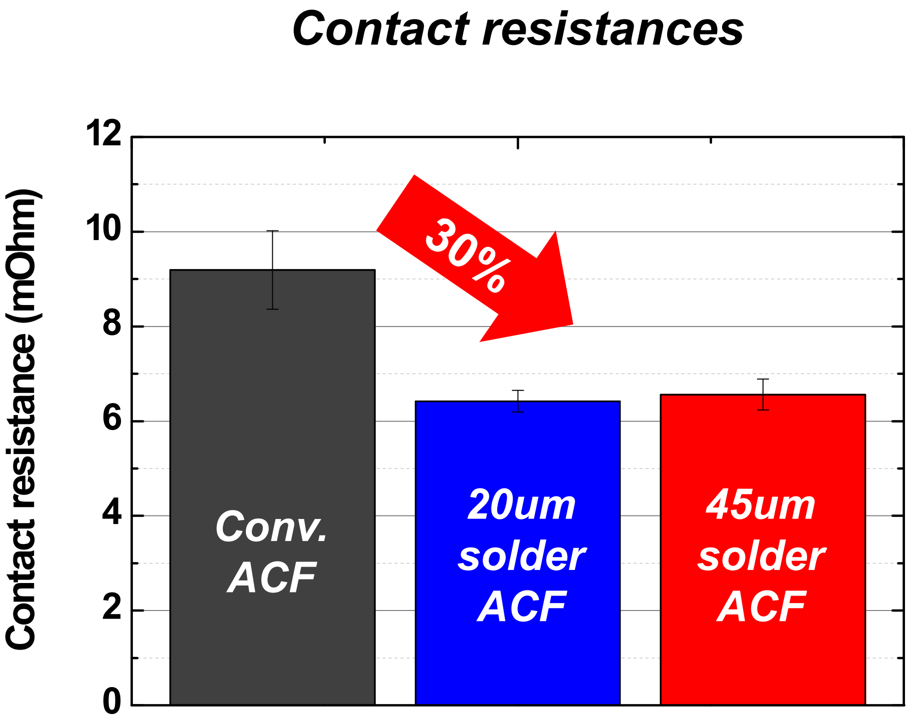
- T/C bonding induces **thermal damages** to boards
- **No thermal damages by U/S**
  - No bonding tool heating
- Very effective on **FOB** (organic PCBs) such as **PET or PC based Touch Screen Panel (TSP)** and **flexible display (polymer OLED)** assembly

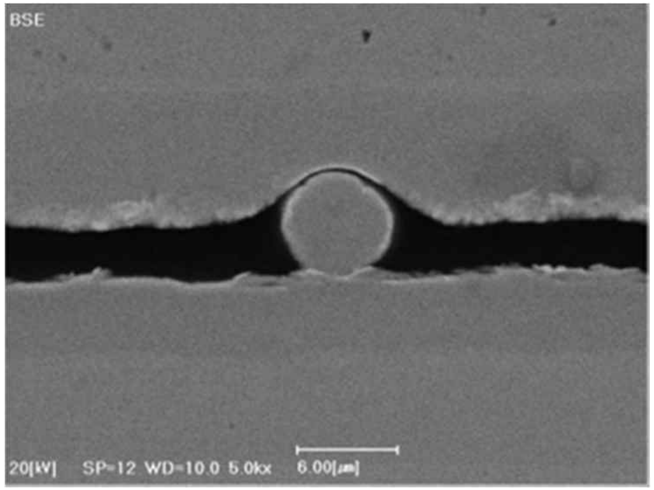
3. Eco-Processing

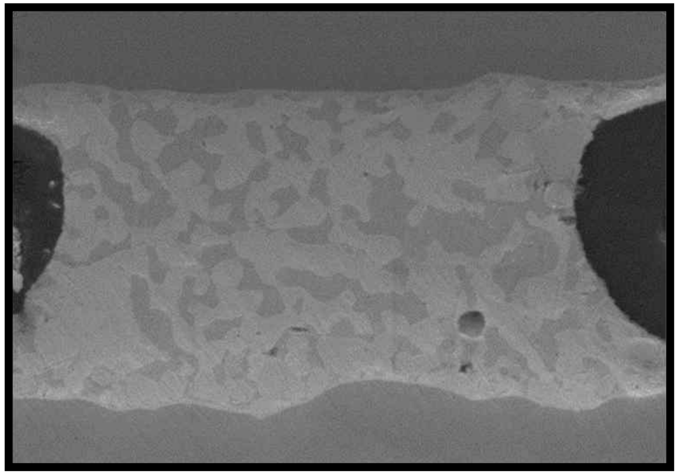
- **Significant energy saving**
  - Very little U/S loading cycle
  - No idling energy loss – digital control

Solder ACF joints - Contact resistance

Conventional T/C : 160 °C 2MPa 6 sec
U/S : 225 °C 2MPa 5 sec



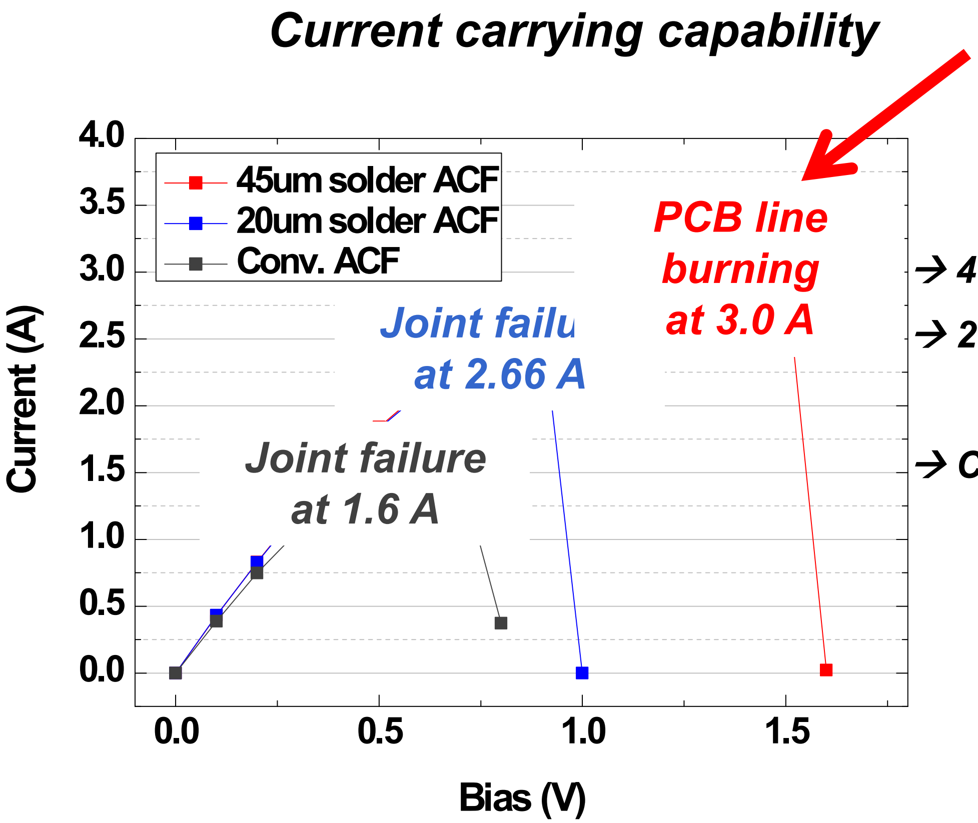




- *The solder ACF joints showed 30% lower contact resistances than that of the conv. Ni ACF joints due to solder alloy bonding of solder particles.*

Conventional T/C : 160 °C 2MPa 6 sec
U/S : 225 °C 2MPa 5 sec

Solder ACF joints - Current carrying capability



Line width : 160 um
Line thickness : 18 um

→ 45um solder ACF
→ 20um solder ACF
→ Conv. ACF

>30%
60%

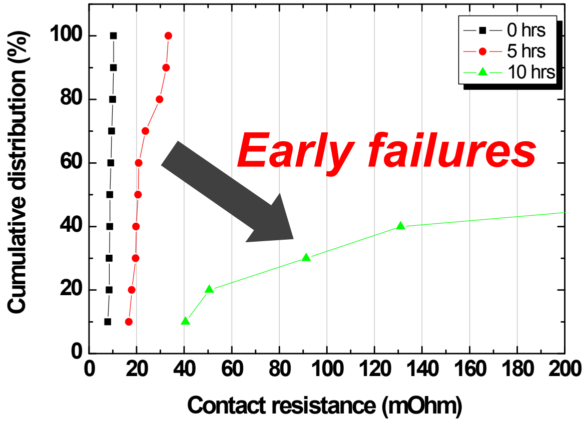
- ***The PCB line burns before ACF joint failure.***
- ***At least 4X increase of power handling capability (1 Watt → 4 Watt)***

Conventional T/C : 160 °C 2MPa 6 sec
U/S : 225 °C 2MPa 5 sec

Solder ACF joints - Reliability

***Unbiased autoclave test* results** *(121 °C, 2 atm, 100%RH, 48 hrs)*

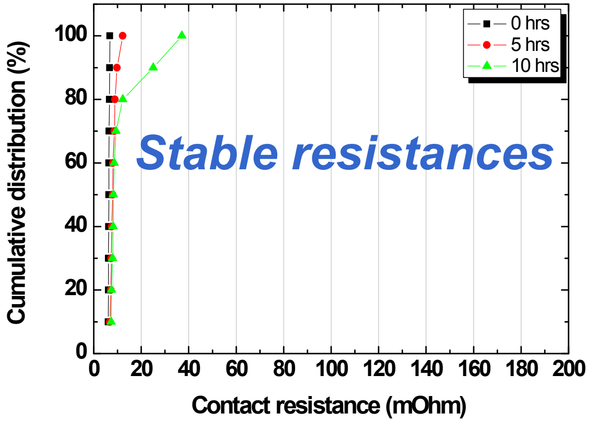
Conventional Ni ACF



Early failures

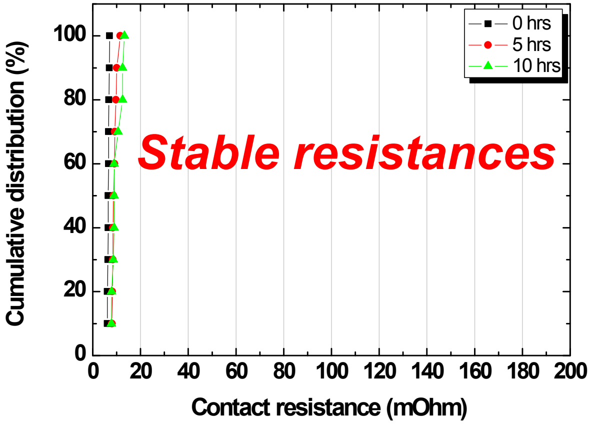
Rapid degradation of physical point contacts

20 um solder ACF



Stable resistances

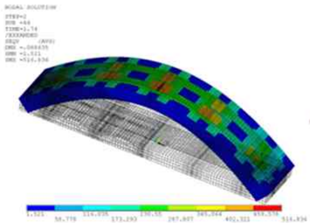
45 um solder ACF

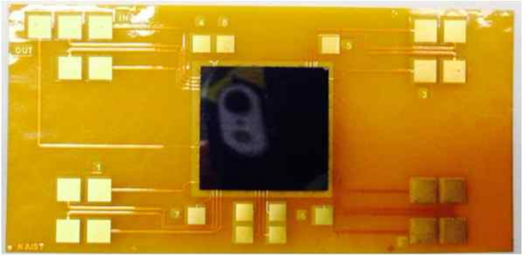


Stable resistances

Summary





For flexible packaging & interconnect for wearable electronics applications,

1. *ACF COF & CIF packages provide excellent chip flexibility by optimizing PKG structure design and ACF materials and processing.*
2. *And ACF FOB & FOF & Fabric assembly using solder ACFs combined with Ultrasonic bonding offer 30 lower joint resistance, >4X power handling capability, high reliability, and great flexibility for wearable electronics applications!*