Flexibility Testing of Printed and Wearable Electronics

Weifeng Liu, Ph.D., William Uy, Jie Lian, Ph.D., Zhen Feng, Ph.D., Anwar Mohammed, Murad Kurwa, Dennis Willie, Victor Najar, Hector Marin

Advanced Engineering Group, FLEXTRONICS Intl.

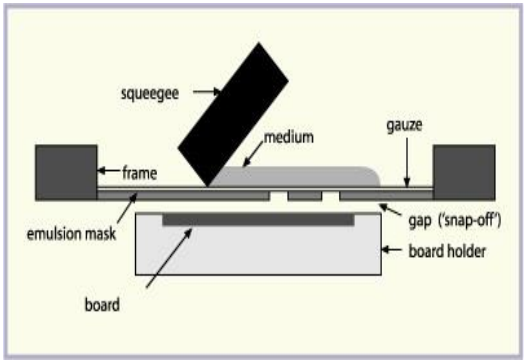
847 Gibraltar Drive, Milpitas, CA 95035

Outline

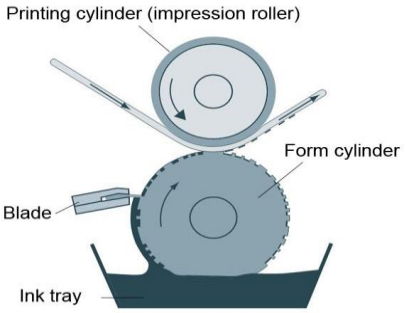
- Introduction to printed and wearable electronics
- Flexibility testing challenges
- Proposals for flexibility testing
- Validation case studies
- Future work

Printed Electronics

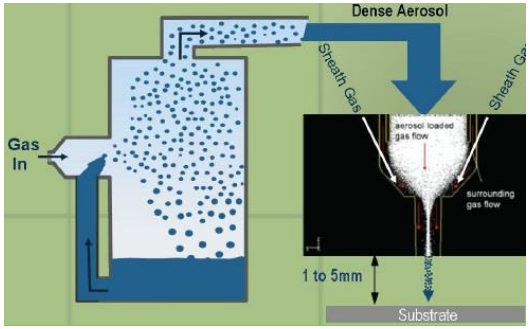
Typical printing processes



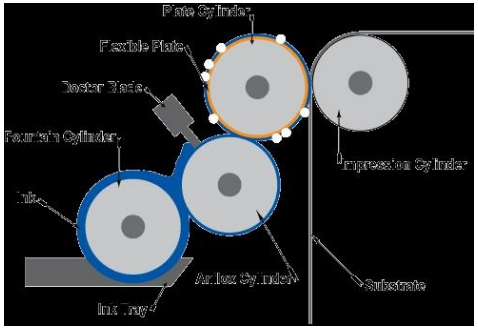
Screen printing



Gravure printing

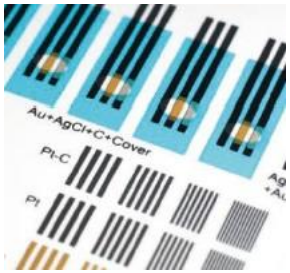


Aerosol jetting

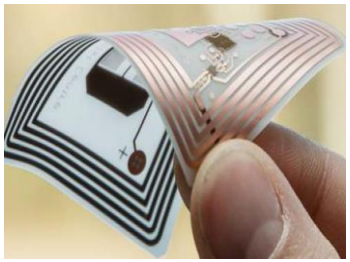


Flexography printing

Typical PE products



Bio sensor

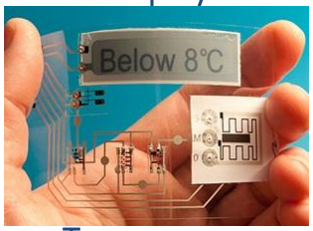


RFID

E-paper

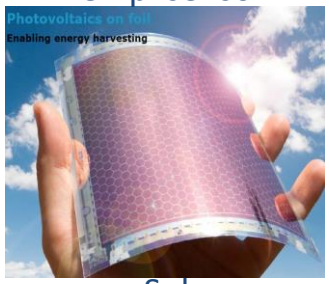
Display

Memory



Temp. sensor

Battery



Solar

Wearable Electronics

SOURCE: BEECHAM 2013 REPORT

SOURCE: Holst

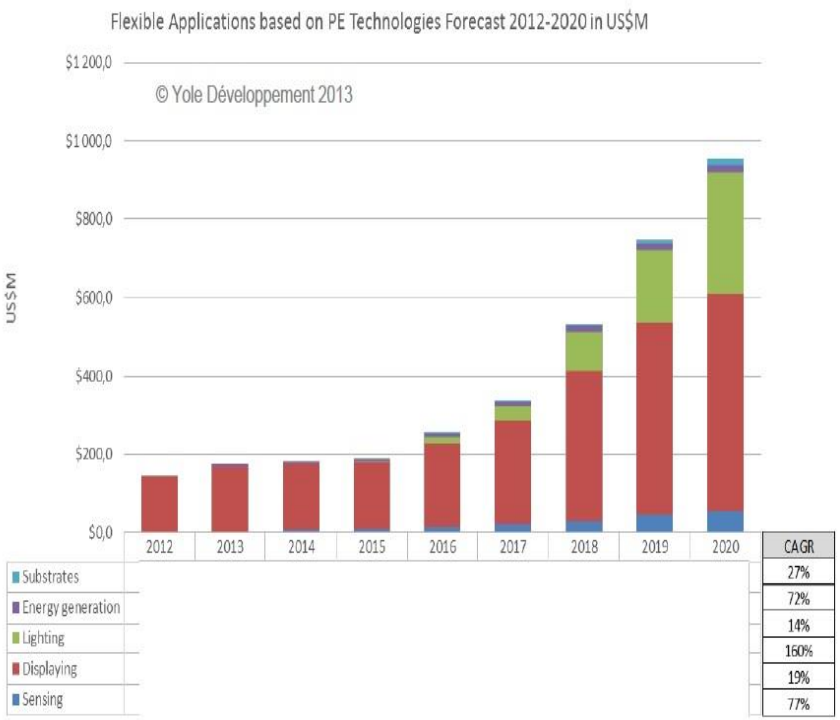
Smart clothing

Biomedical shirt

SOURCE: *T. Morrison et al., University of Washington*

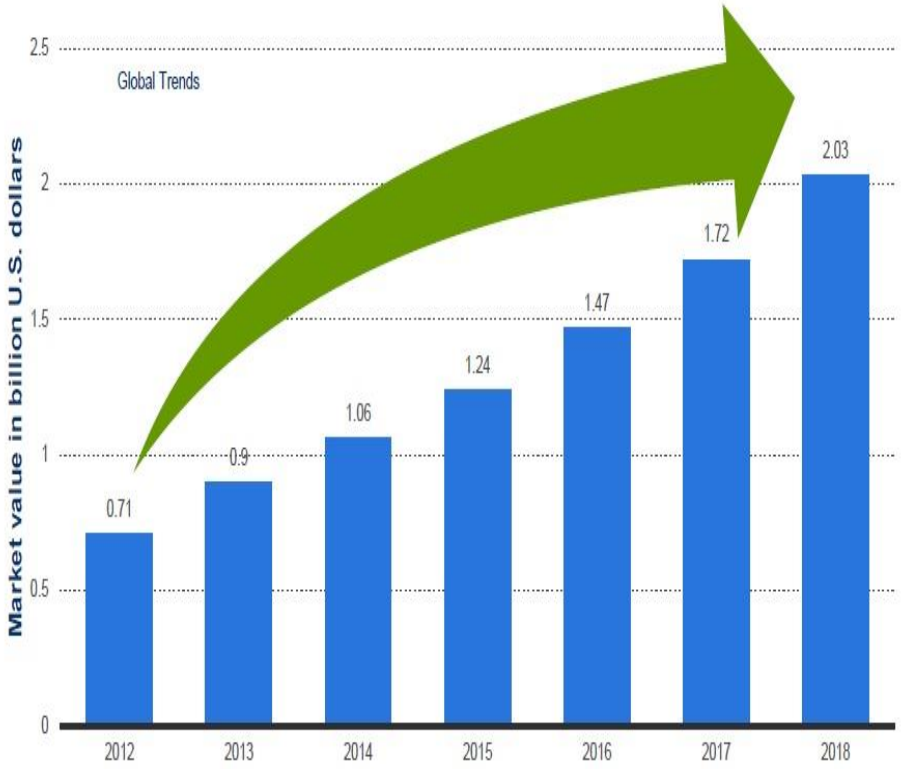
Printed and Wearable Electronics

Flexible & Printed Applications Market for the Different Functions (in US$M)



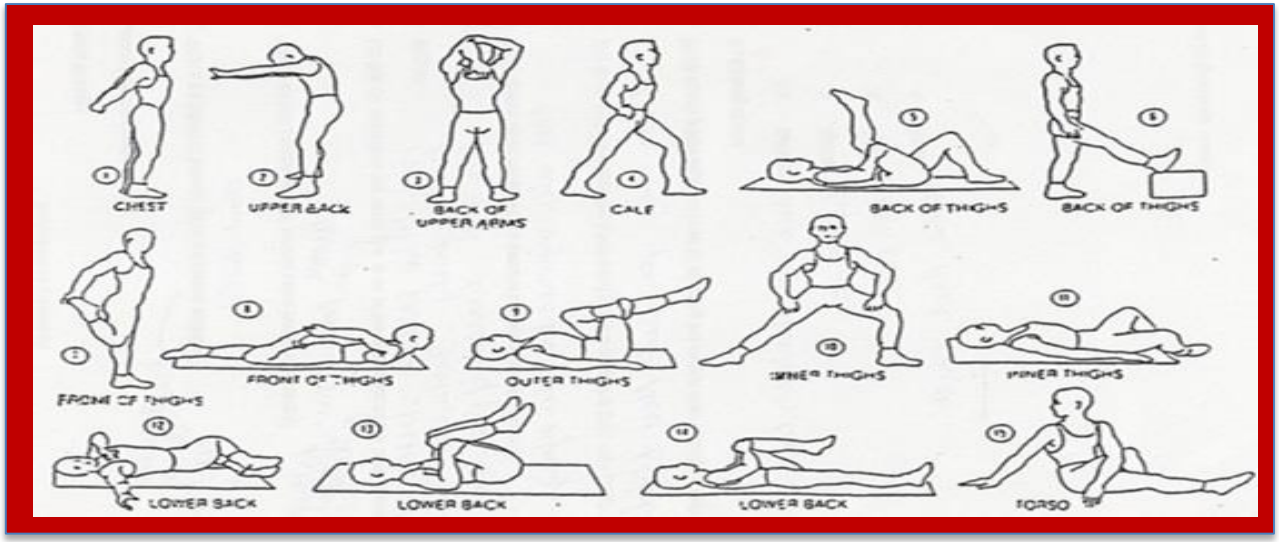
Source: Semicon West 2013
http://www.semiconwest.org/sites/semiconwest.org/files/docs/SW2013_Christophe%20Fitamant_Yole%20Developpement.pdf

Smart Fabrics/Textile Market Revenue Forecast from 2012 to 2018 (in US$B)



Source: Markets and Markets
http://www.marketsandmarkets.com/

Printed and Wearable Electronics Application Conditions



Flexibility Challenges for Wearable Applications

- **Wearable electronics will experience different types of flexibility stresses:**
  - **Stretching**
  - **Bending**
  - **Torsion**
  - **Twisting**
  - **Crumpling**
  - **Others**

- **It is challenging to generalize a set of fixed flexibility tests to simulate or duplicate all the actual use conditions**

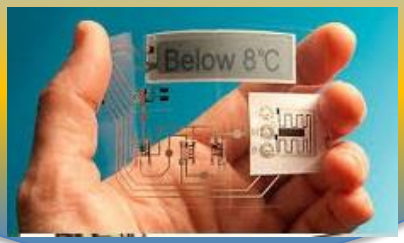
- **No flexibility testing standards available, solely developed for wearable and printed electronics**

- **No universal equipment currently available to accommodate all the tests**

Our Approach

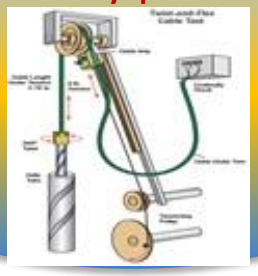
Available standards

Potential use conditions

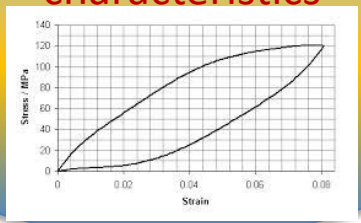


- Leverage current standards with/without modification
- Develop new methods referencing current industry practices
- Develop new test methods
- Design/build a universal tester

Industry practices



Material/design characteristics

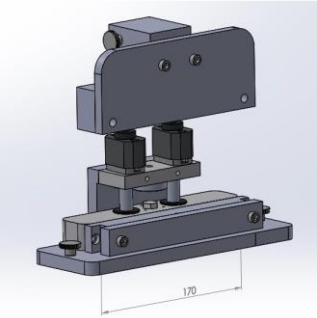


Flexibility Testing

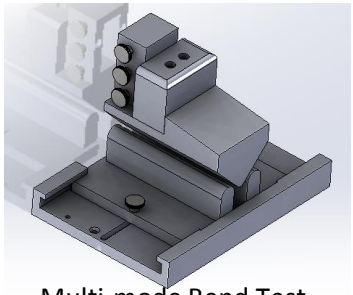
- **Stretchability test**
- **Bending test**
  - **Variable angle bending**
  - **Folding test**
  - **Free Arc bending**
  - **Variable radius bending**
  - **Spherical bending**
- **Torsion test**
  - **Torsion**
  - **Twisting**
- **Rolling test**
  - **Parallel sliding plate**
  - **Rolling flex test**
- **Crumple compression test**
- **Combined or time dependent stresses**
  - **Stretchability + twisting**
  - **Rolling + torsion**
  - **Constant stretching**
  - **Constant bending**

- **Programmable parameters:**
  - Force
  - Displacement
  - Speed
  - Angle
  - Holding time
  - Repeating cycle
- **Monitoring attributes:**
  - Resistance
  - Functionality
  - In situ or periodically
- **Fixture design**
  - Mandrel diameter
  - Sharp edge/chamfer
  - Mandrel material (rubber vs steel)
  - Sample preparation (with/without carrier)

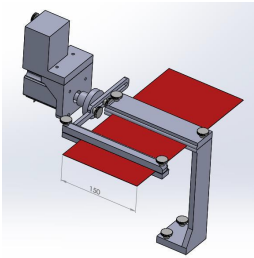
Universal Flexibility Tester



Stretchability test

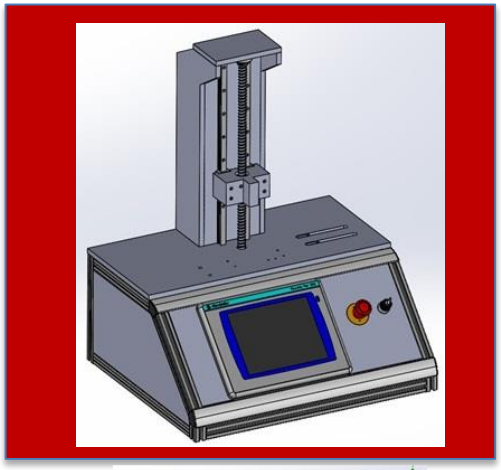


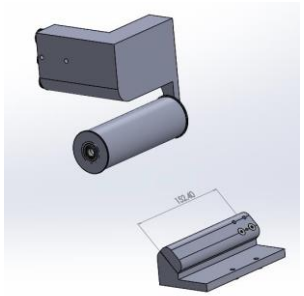
Multi-mode Bend Test



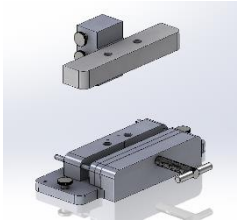
Variable Angle Bend Test

Variable Radius Test
Sliding Plate Test

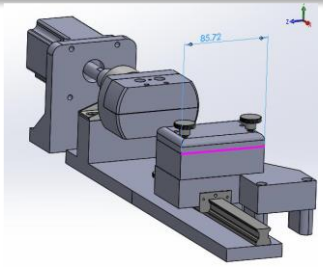




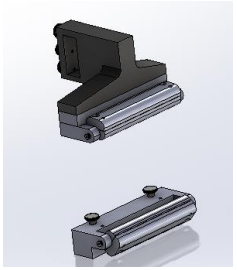
Variable Diameter Rolling Test



Compression Test



Multi Modal Torsion Test



Free Arc Bend Test

Stretchability Testing

Test Purposes

- To determine the stretching limit of circuit by uniaxial tensile force
- To determine the stretching fatigue of circuit at repeated tensile load
- To determine recoverability under prolonged stretching conditions

Test Samples

- Samples may be prepared in straight edge strips or in “dogbone” strip as described in ASTM E-345.
- Custom product samples

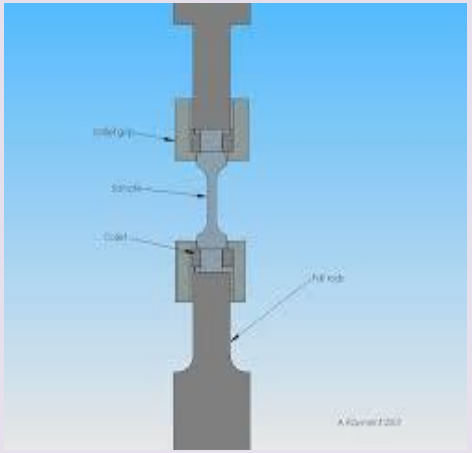
Attributes Monitoring

- In situ resistance monitoring
- Functional check up every XXX cycles
- Physical check up

Simulated Use Conditions

- Stretchable ECG skin patch
- Biometric clothing (compression shirt, underwear, sock)

Test Setup



Standard References

- ASTM E-345 Standard Test Methods of Tension Testing of Metallic Foil
- IPC-TM-650, 2.4.18 Tensile Strength and Elongation, Copper Foil
- IPC-TM-650, 2.4.18.1 Tensile Strength and Elongation, In House Plating
- ASTM E606-12 Standard Test Method for Strain-Controlled Fatigue Testing.
- ASTM E466-07 Standard Practice for Conducting Force Controlled Constant Amplitude Axial Fatigue Tests of Metallic Materials
- ASTM D882-12 Standard Test Method for Tensile Properties of Thin Plastic Sheeting

Torsion /Twisting Test

Test Purposes

- To determine the torsion or twisting limit of flexible circuit
- To verify if the flexible circuit remains functional throughout repeated torsion/twisting operations (without or with tension)

Test Samples

- Samples may be prepared in straight edge strips or in “dogbone” strip as described in ASTM E-345.
- Samples may be mounted on a carrier
- Custom product samples

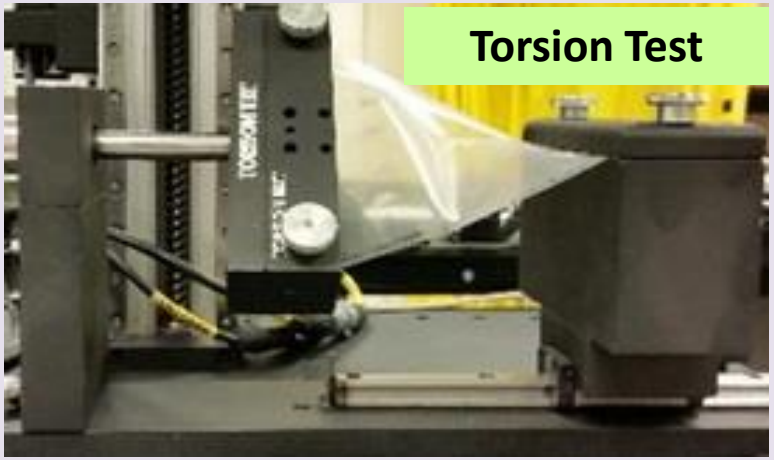
Attributes Monitoring

- In situ resistance monitoring
- Functional check up every XXX cycles
- Physical check up

Simulated Use Conditions

- Biometric compression shirt
- Wristband (e.g., X Torsion SmartPhone)

Test Setup



Standard References

- **ASTM A938 - 07(2013)** Standard Test Method for Torsion Testing of Wire

Rolling Flex Test

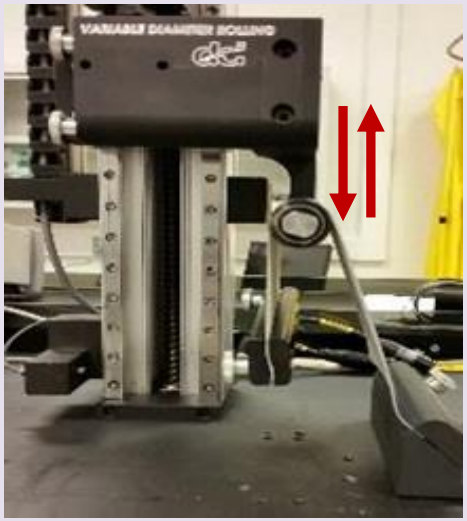
Test Purposes

- To evaluate the functionality of flexible circuit devices under repeated bending and rolling conditions.

Simulated Use Conditions

- Roll-to-roll manufacturing process (e-paper, flexible display, etc)

Test Setup



Test Samples

- Samples may be prepared in straight edge strips
- Samples may be mounted on a carrier
- Custom product samples

Attributes Monitoring

- In situ resistance monitoring
- Functional check up every XXX cycles
- Physical check up

Standard References

- **IPC-TM-650 2.4.2.1 Flexural Fatigue and Ductility, Foil.**
- **IPC-TM-650 2.4.3E Flexural Fatigue, Flexible Printed Wiring Materials.**

Variable Angle Bending Test

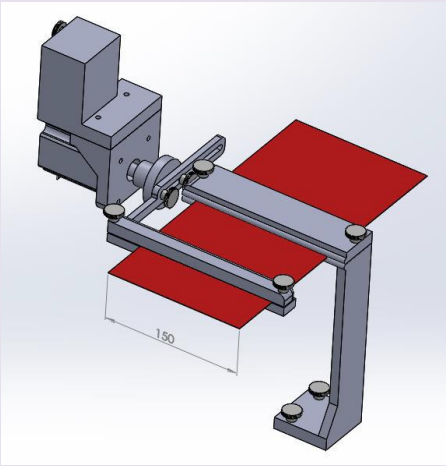
Test Purposes

- To determine the bending limit of flexible circuit
- To evaluate the functionality of flexible circuit devices under repeated bending conditions

Simulated Use Conditions

- Elbow flex sensor
- Posture sensor

Test Setup



Test Samples

- Samples may be prepared in straight edge strips
- Samples may be mounted on a carrier
- Custom product samples

Attributes Monitoring

- In situ resistance monitoring
- Functional check up every XXX cycles
- Physical check up

Standard References

- IPC-6013C Qualification and Performance Specification for Flexible Printed Boards
- IPC-2223C Sectional Design Standard for Flexible Printed Boards

Sliding Plate Test

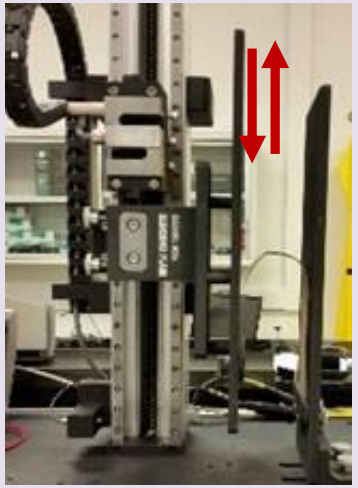
Test Purposes

- To evaluate the functionality of flexible circuit devices under repeated sweeping motion and constant bending conditions

Simulated Use Conditions

- Re-position of smart watch/wristband
- Wear on/off of Biomedical compression shirt

Test Setup



Test Samples

- Samples may be prepared in straight edge strips
- Samples may be mounted on a carrier
- Custom product samples

Attributes Monitoring

- In situ resistance monitoring
- Functional check up every XXX cycles
- Physical check up

Standard References

- None

Variable Radius Bending Test

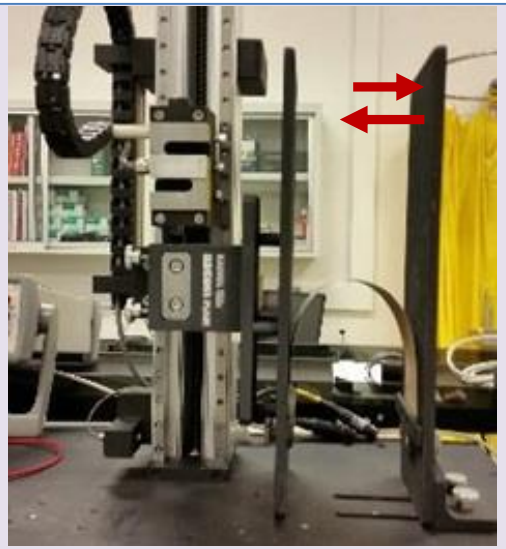
Test Purposes
- To evaluate the functionality of flexible circuit devices under repeated bending conditions with variable bending radius.

Test Samples
- Samples may be prepared in straight edge strips
- Samples may be mounted on a carrier
- Custom product samples

Attributes Monitoring
- In situ resistance monitoring
- Functional check up every XXX cycles
- Physical check up

Simulated Use Conditions
- Smart watch/wristband wear on/off
- Headband wear on/off

Test Setup

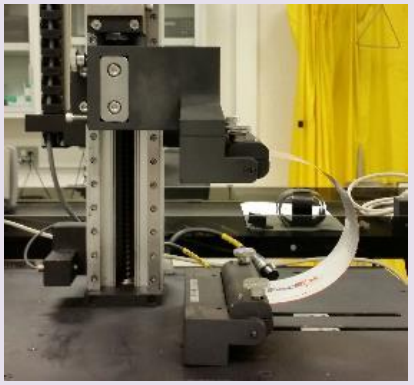
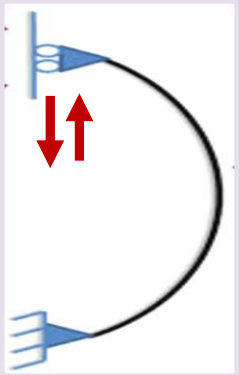


Standard References
- None

Free Arc Bending Test

Test Purposes
- To verify that flexible circuit devices under test remain functional throughout repeated bending operations.

Simulated Use Conditions
- Smart watch/wristband wear on/off
- Headband wear on/off

Test Setup



Test Samples
- Samples may be prepared in straight edge strips
- Samples may be mounted on a carrier
- Custom product samples

Attributes Monitoring
- In situ resistance monitoring
- Functional check up every XXX cycles
- Physical check up

Standard References
- None

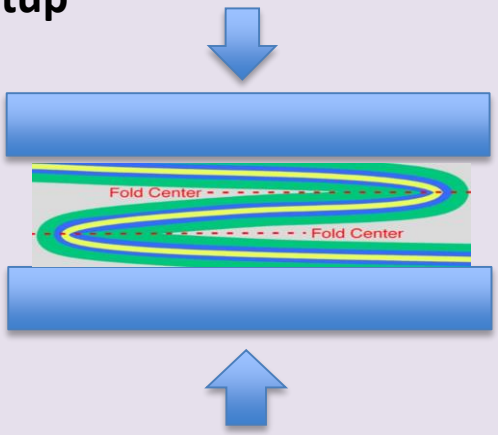
Folding Test

Test Purposes
- To evaluate the functionality of flexible circuit devices under repeated folding conditions.

Simulated Use Conditions
- Folding of smart shirt/jacket
- Folding of e-paper/flexible display

Test Samples
- Samples may be prepared in straight edge strips or other shapes
- Samples may be mounted on a carrier
- Custom product samples

Test Setup



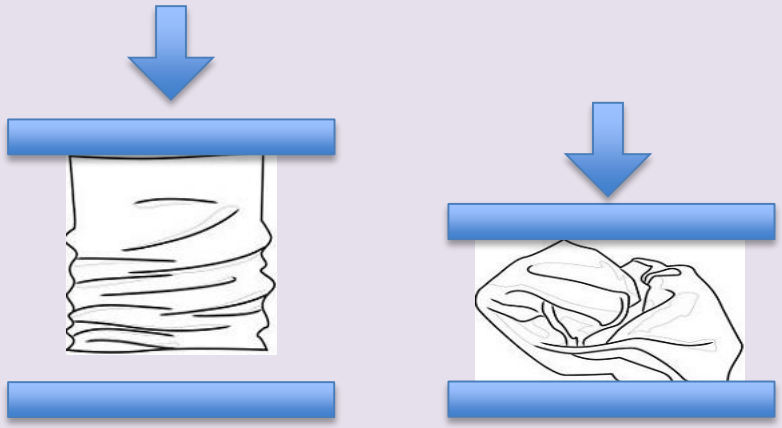
Attributes Monitoring
- In situ resistance monitoring
- Functional check up every XXX cycles
- Physical check up

Standard References
- IPC-TM-650 2.4.5 Folding Endurance, Flexible Printed Wiring Materials

Crumple Compression Test

Test Purposes
- To verify that flexible circuit devices under test remain functional throughout repeated crumpling operations.

Simulated Use Conditions
- Smart textile wrinkles
- Wearable under compression

Test Setup


Test Samples
- Samples may be prepared in straight edge strips or other shapes
- Samples may be mounted on a carrier
- Custom product samples

Attributes Monitoring
- In situ resistance monitoring
- Functional check up every XXX cycles
- Physical check up

Standard References
- None

Spherical Bending Test

Test Purposes

- To verify that flexible circuit devices under test remain functional due to repeated flexural loading operations.

Simulated Use Conditions

- Flexible touch screen display
- Wearable key board/guita

Test Samples

- Samples may be prepared in straight edge strips or squares to be mounted on a loop
- Samples may be mounted on a carrier
- Custom product samples

Test Setup

Attributes Monitoring

- In situ resistance monitoring
- Functional check up every XXX cycles
- Physical check up

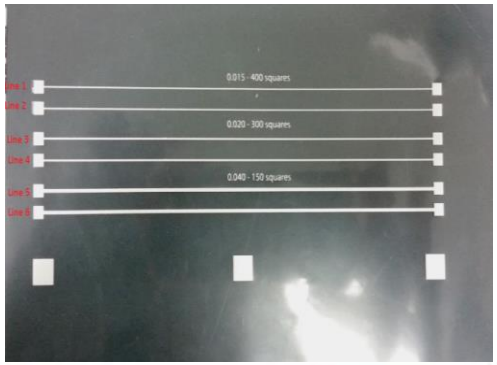
Standard References

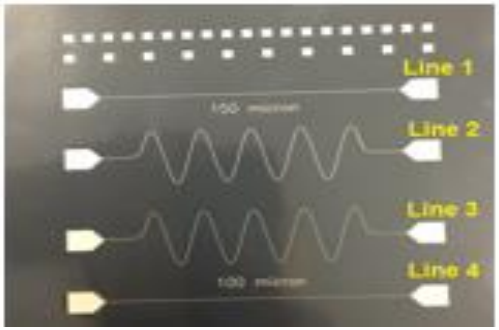
- IPC 9707: Spherical Bend Test Method for Characterization of Board Level Interconnects
- IPC 9702: Monotonic Bend Characterization of Board-Level Interconnects

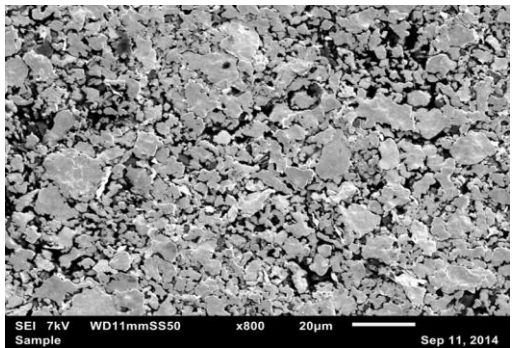
Developed

CASE STUDY: Stretchability Testing

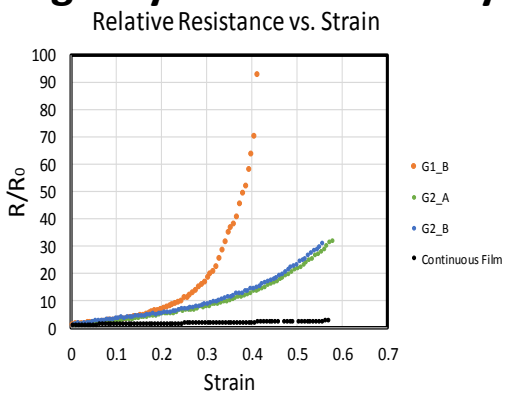
Samples: Silver ink on TPU



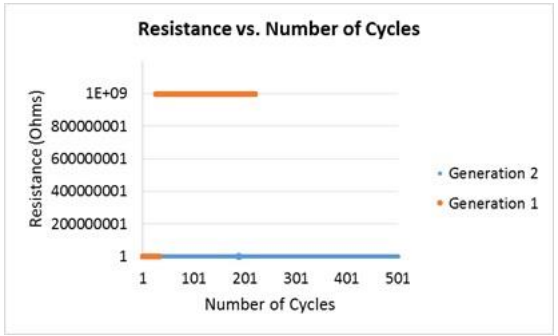




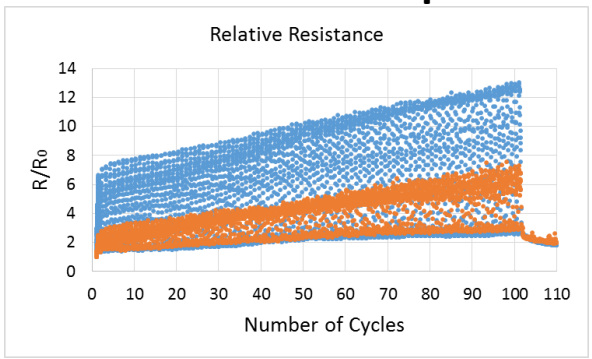
Single Cycle Stretchability



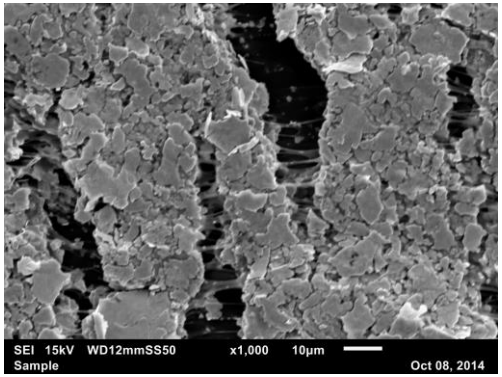
Repeated Stretchability



Printed Pattern Comparison



Ink Crack during Stretching



Summary

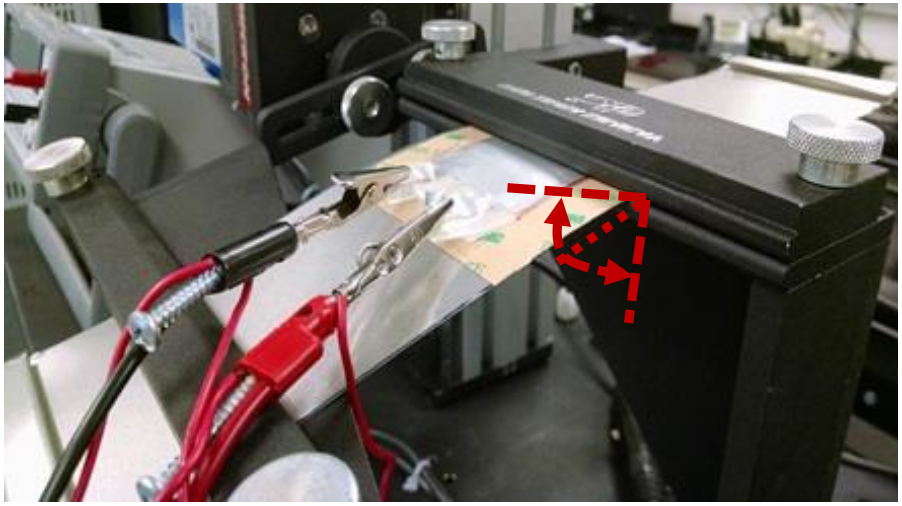
- Ink microstructure and design pattern have a great impact on conductivity during stretchability testing

CASE STUDY: Variable Angle Bending Test

Thin Battery

Battery Mounted on Al Foil Strip

Battery under Test (+/-15° bending angle)

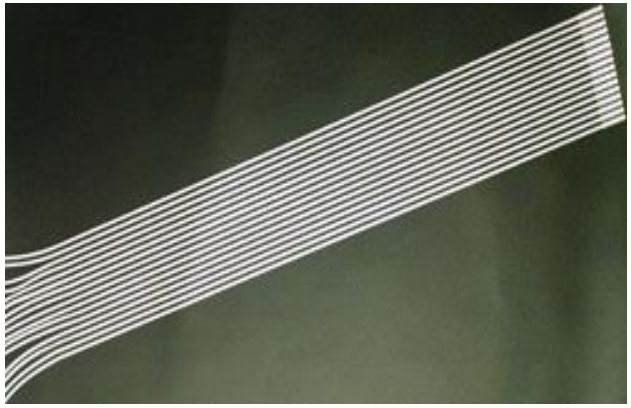


Summary

- Battery shows gradual drop in voltage during the process
- No delamination between battery and Al foil (double tape strong enough)

CASE STUDY: Crumple Compression Test

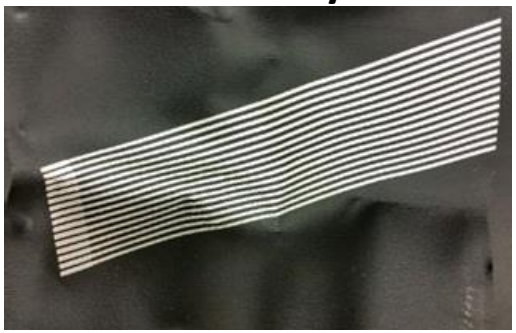
Printed Ink

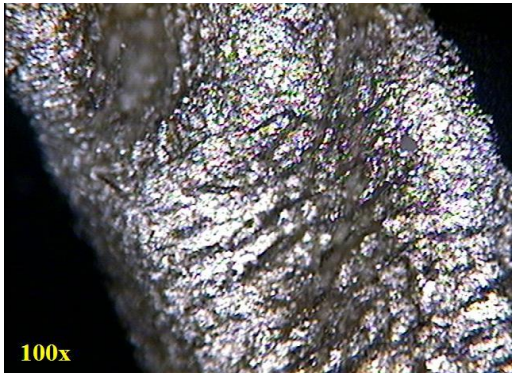


Ink material: Silver
Substrate: Vinyl

Crumpling Test

After 1000 cycles



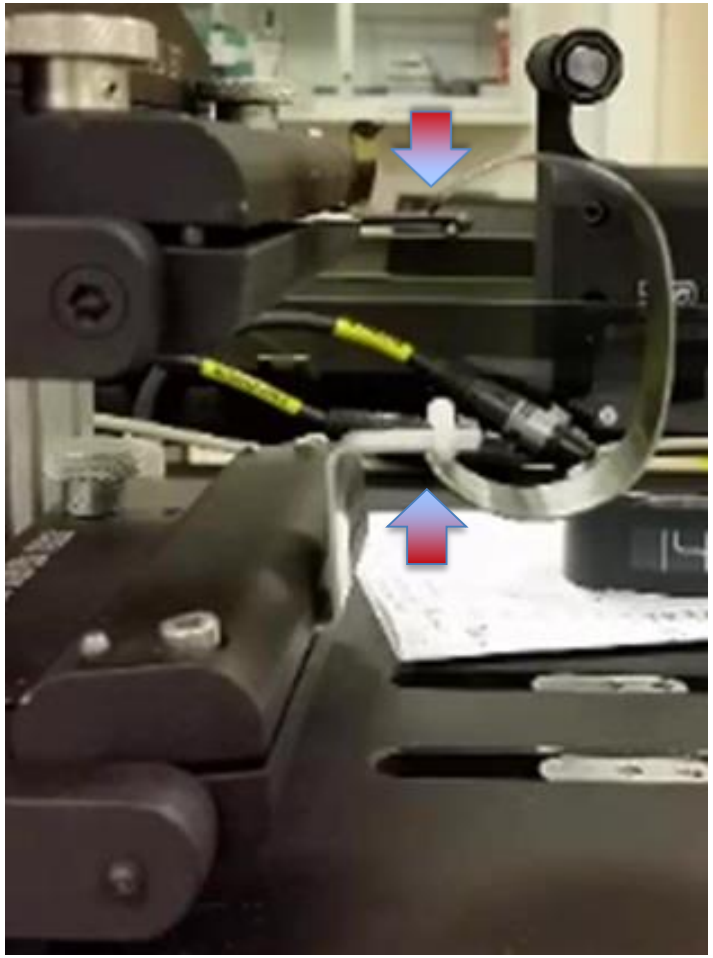


Summary

- Resistance of the ink traces increased from 6 ohms to 12 ohms after 1000 cycle crumpling test
- Some damages on the ink traces (separation from substrate, wrinkle, crack)

CASE STUDY: Free Arc Bending

Free Arc Bending Test

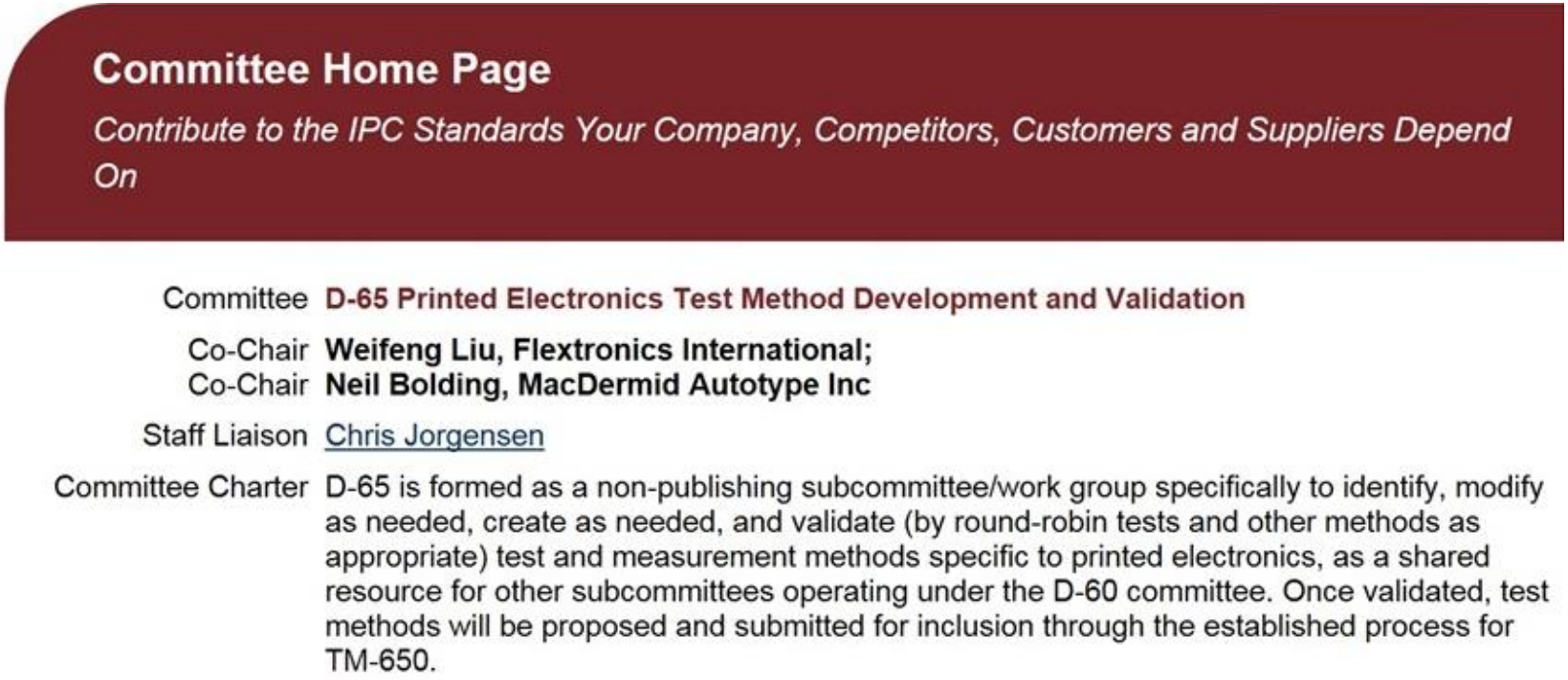


Summary

- Free arc bending test on a wristband to simulate wear on/off
- The wristband is functioning after 2000 cycles repeated bendings

Future Work

- Continue working on test method development and validation
  - Correlation with actual use conditions
  - Test method standardization



Committee Home Page

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Committee	**D-65 Printed Electronics Test Method Development and Validation**
Co-Chair	**Weifeng Liu, Flextronics International;**
Co-Chair	**Neil Bolding, MacDermid Autotype Inc**
Staff Liaison	Chris Jorgensen
Committee Charter	D-65 is formed as a non-publishing subcommittee/work group specifically to identify, modify as needed, create as needed, and validate (by round-robin tests and other methods as appropriate) test and measurement methods specific to printed electronics, as a shared resource for other subcommittees operating under the D-60 committee. Once validated, test methods will be proposed and submitted for inclusion through the established process for TM-650.

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Thank you for attending!

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