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Embedding of Active Components in LCP for Implantable Medical Devices

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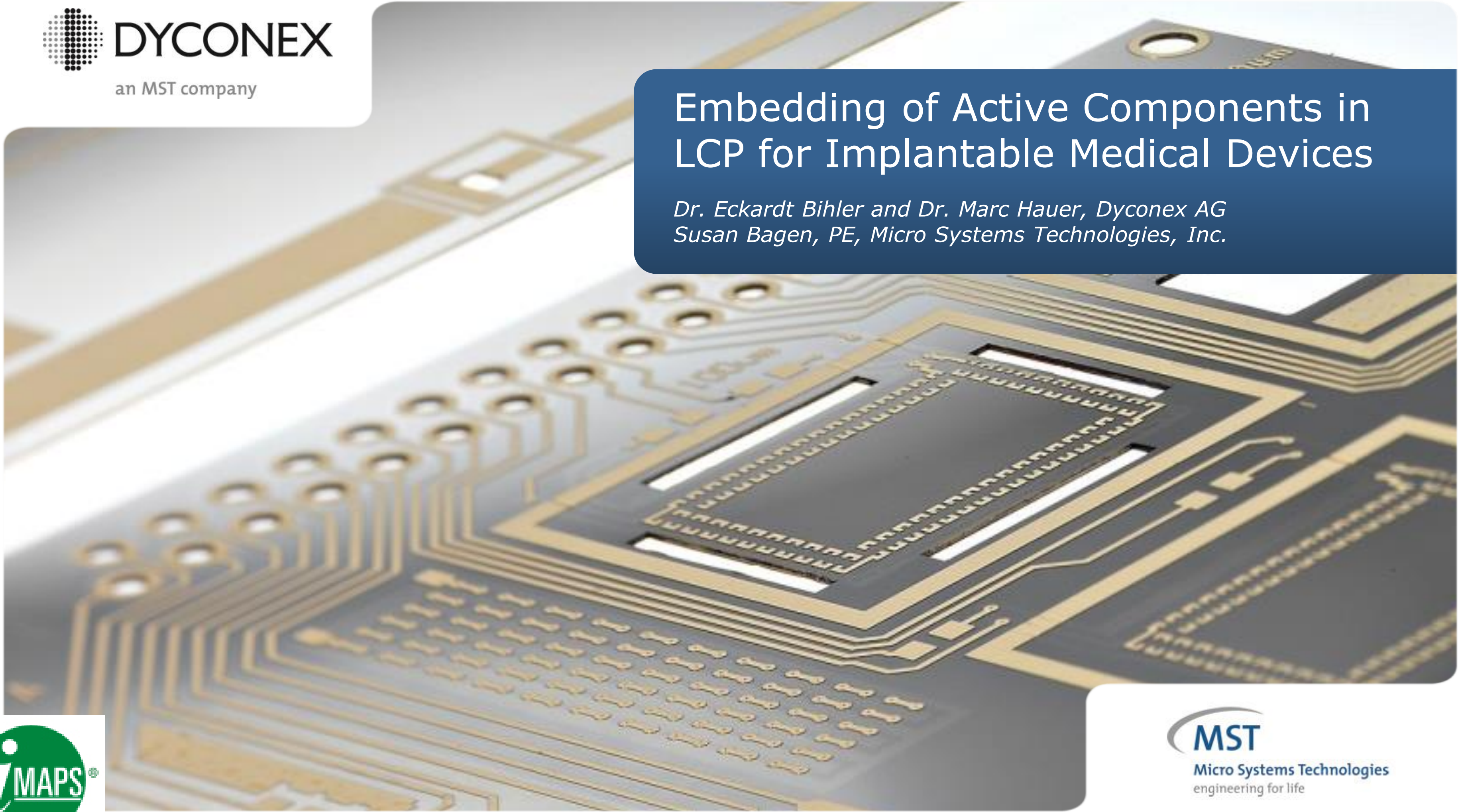

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BACKGROUND AND GOALS

Liquid crystal polymer (LCP) dielectric has been demonstrated as feasible for producing directly implantable, biocompatible structures without the need for hermetic coatings or housings [1,2].

- Neural interfaces and electrodes can be fabricated based on flex circuit manufacturing techniques using biocompatible material sets
- Achieve significantly smaller form factors
- Incorporate complex features, channels and routings through the use of photolithography and laser drilling
- Enhancing functionality by embedding active and passive components within the implantable structures thanks to the very low moisture uptake of LCP

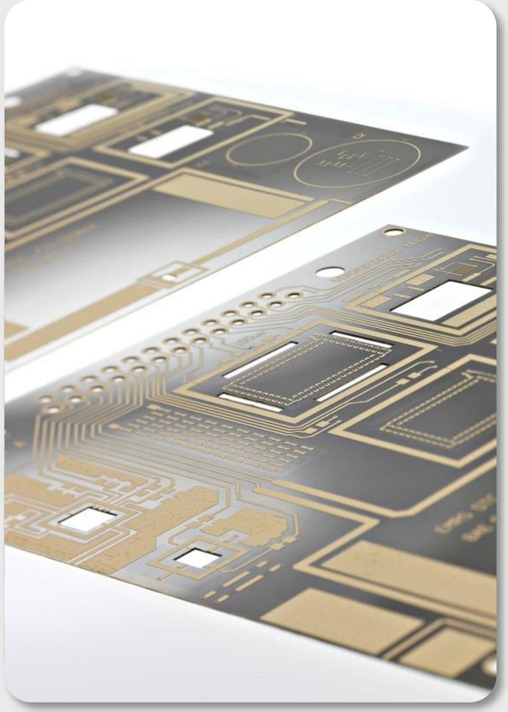
References:

[1] J. Jeung, et al., "A novel multilayered planar coil based on biocompatible liquid crystal polymer for chronic pain implantation," *Sensors and Actuators A: Physical*, Volume 197, 1 August 2013, pp. 38-46.

[2] S.W. Lee, et al., "Development of Microelectrode Arrays for Artificial Retinal Implants Using Liquid Crystal Polymers," *IOVS*, December 2009, Vol. 50, No. 12, pp. 5859-5866.

LIQUID CRYSTAL POLYMER (LCP) PROPERTIES

- LCP is a thermoplastic material
- Operating temperature up to 190° C
- Melting point at 280°C
- Can be transfer molded to any shape
- Density 1.4 g/cm3
- Low water absorption < 0.04%
- Fully biocompatible according to ISO 10993-5 (in vitro cytotoxicity)

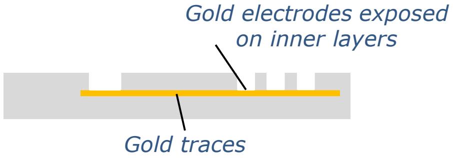


EXAMPLES OF BIOCOMPATIBLE LCP STRUCTURES

Electrodes and neural interface structures fabricated on conventional flex circuit manufacturing equipment combined with thin film technology

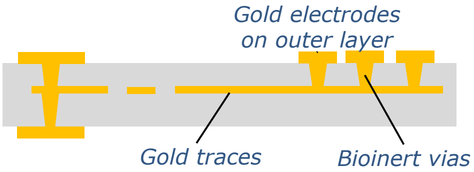
Single layer

- **Biocompatible material**
- **Biocompatible conductor**
- **Au / Pt pads**



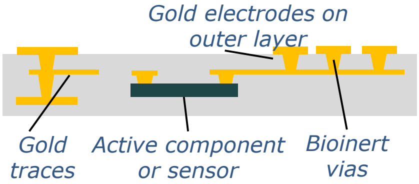
Multilayer

- **Biocompatible material**
- **Biocompatible conductor**
- **Biocompatible vias**



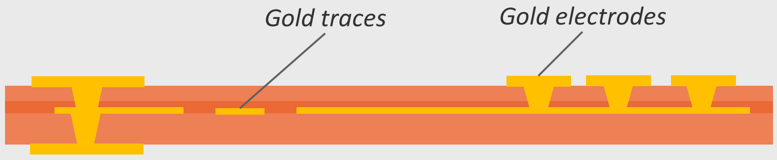
Bioinert package

- **Biocompatible material & conductor**
- **Biocompatible vias**
- **Embedded dies**



BIOCOMPATIBLE CONDUCTOR TECHNOLOGY

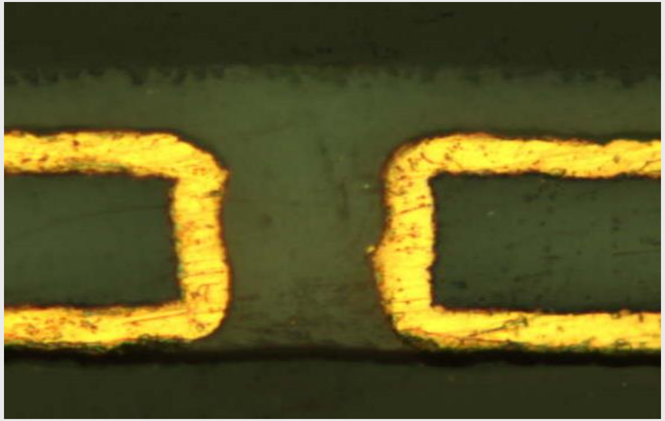
- Conductor material pure gold
- Minimum line width 30 µm
- Minimum spacing between traces 20 µm
- Conductor thickness between 2…15 µm
- Line resistance between 0.1…1 Ω/cm
- Resistance has a linear temperature coefficient and can be used to measure temperature



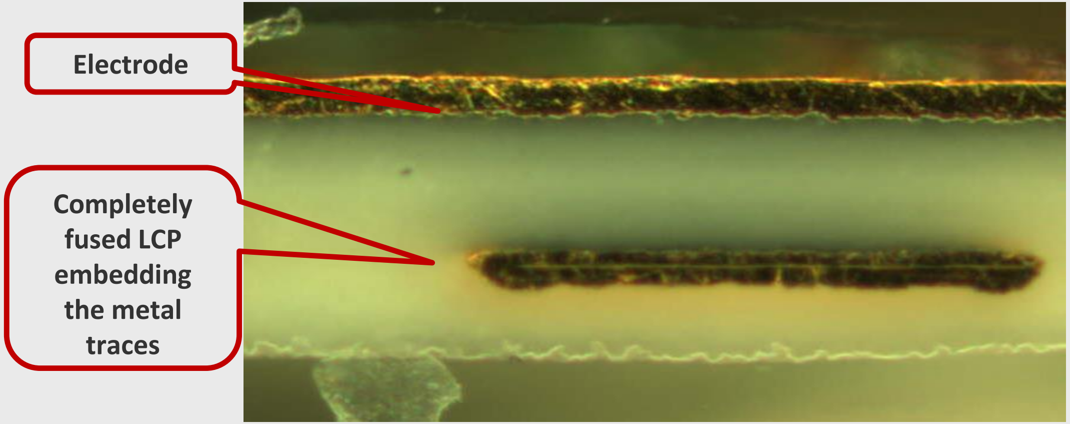
Completely Biocompatible Structure

LCP lead structure with electrodes on the surface and embedded metal traces from pure gold

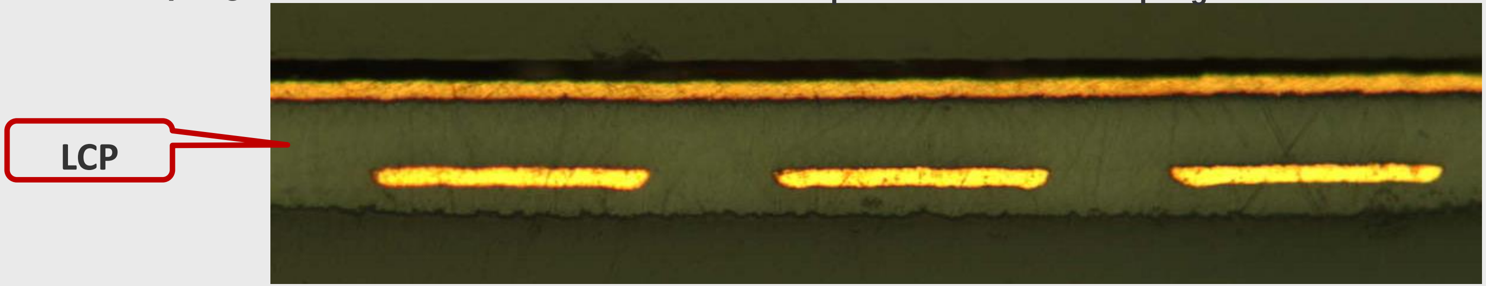
NOBLE METAL TRACES AND VIAS



75 µm diameter via with 15 µm gold thickness



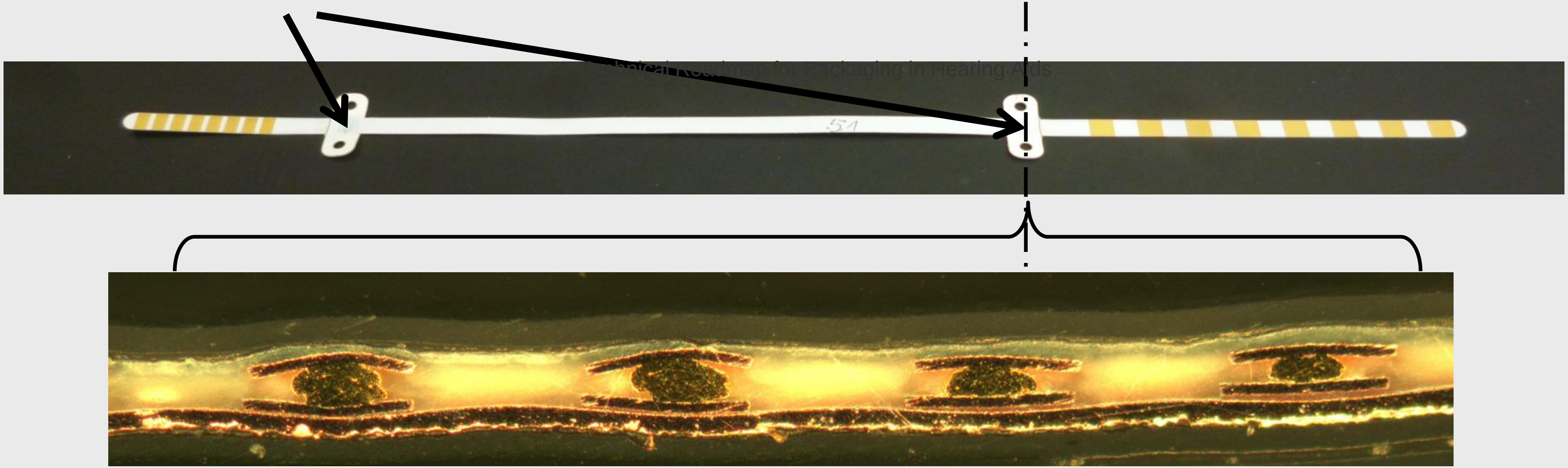
120 µm wide trace with 15 µm gold thickness



120 µm wide traces with 60 µm spacing in 75 µm thick LCP structure with electrode on top

SEALED INTERCONNECTS BETWEEN CABLES

- New fully biocompatible interconnect technology for implanted leads
- Extension of maximum lead length
- Solderless & glueless
- Local applied heat pulse under pressure melts LCP and seals contacts
- Pull strength 20 N/mm - same as lead body



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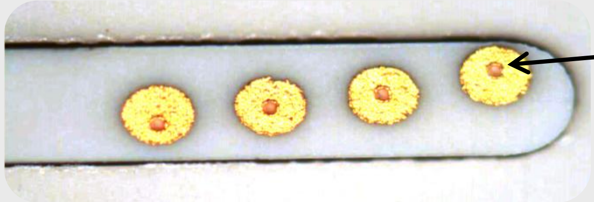
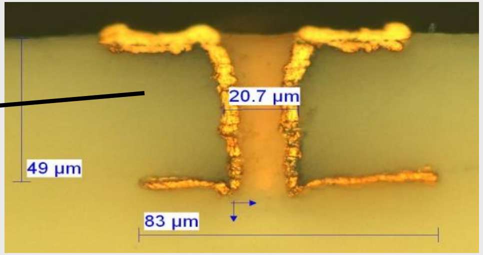
HIRES TIP ELECTRODE

High resolution with pure gold traces for biocompatible, neurostimulation electrode

Tip width:	300 µm
Distance between electrodes:	250 µm
Electrode diameter:	100 µm





Metallized via 20 µm

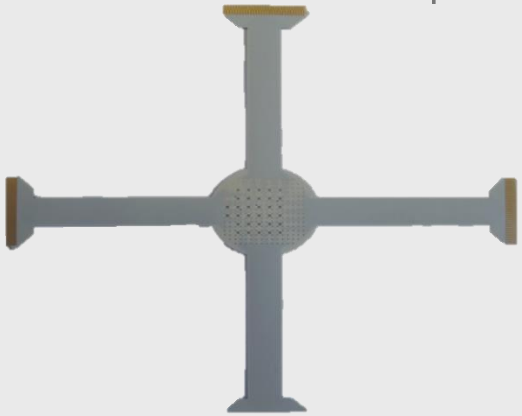
Embedded traces on backside with trace width of 30 µm

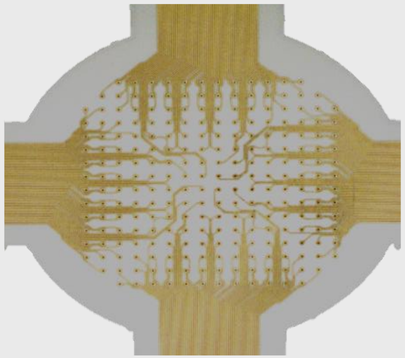
↔ 100 µm

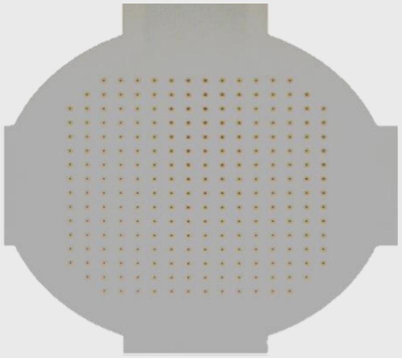
HIGH RESOLUTION ELECTRODE FOR BRAIN INTERFACE

Application: Implanted electrode for 4 x 64 Channel EEG for animal tests

- 16 x 16 Matrix of electrodes with 0.75 mm pitch
- Pure gold traces with 30 µm line width/spacing
- Traces embedded in LCP
- Electrode diameter 75 µm







METHODS – RELIABILITY EVALUATION

- LCP film used as the dielectric material with noble metal conductors such as Au, Pt and PtIr
- Appropriate cleaning processes used to ensure biocompatibility of the final structures[3]
- Mock silicon die patterned with Cu embedded within the LCP to produce test structures for hermeticity studies
- Long term biostability evaluations performed by soak tests in heated phosphate-buffered saline (PBS)
- Bend testing at a 0.5 mm radius conducted for mechanical reliability
- Cross-sectional analysis used to examine regions of failure

[3] ISO 10993-1:2009 Biological evaluation of medical devices – Part 1: Evaluation and testing with a risk management process.

TEST CHIP DESIGN

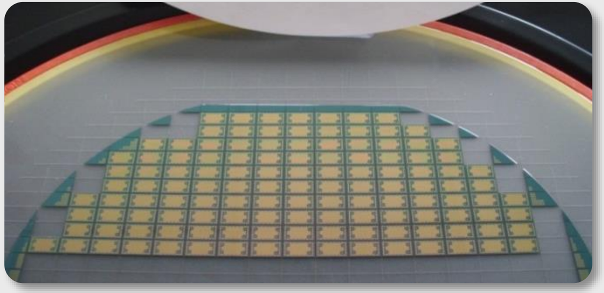
FIGURE 2

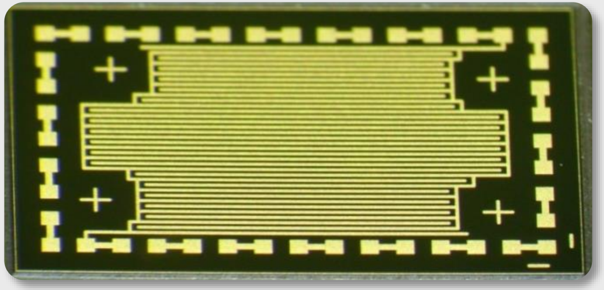
Test chip for embedding

- Manufacturer: TLMI, Austin, Texas
- Wafer diameter: 150 mm
- Active wafer diameter: 147 mm
- Wafer thickness: 100 µm (thinned)
- Die surface: thermal oxide
- Adhesion promoter: TiW (sputtered)
- Metallization: 3 µm copper & gold flash
- Chip dimensions: 5 x 8 mm

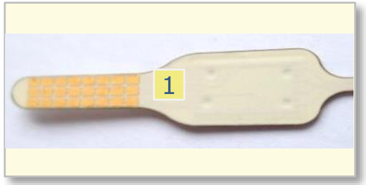
Artwork on die

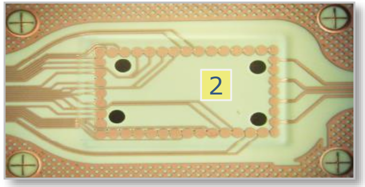
- Pad size: 250 x 250 µm (thinned)
- Interdigitized comb structure with 50 µm lines & spaces

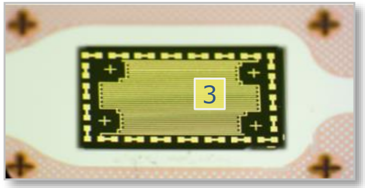




TEST CHIP EMBEDDED IN LCP







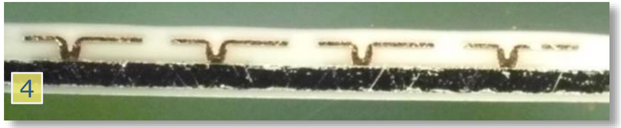
Electrode layer (1)

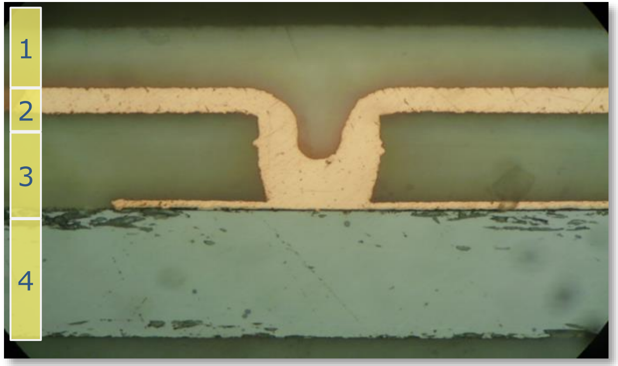
Redistribution layer (2)

Chip pad layer (3)

Backside layer (4)

4-layer LCP multilayer build-up





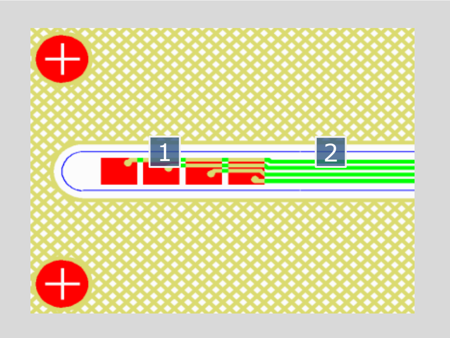
EMBEDDED DIE TEST STRUCTURE FOR SOAK TESTS

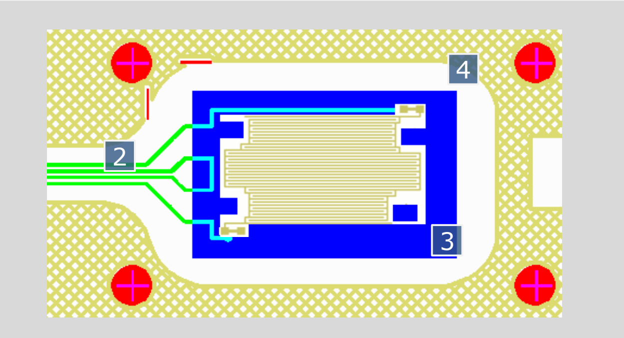
Contact pads on electrode layer (1)

Embedded traces on redistribution layer (2)

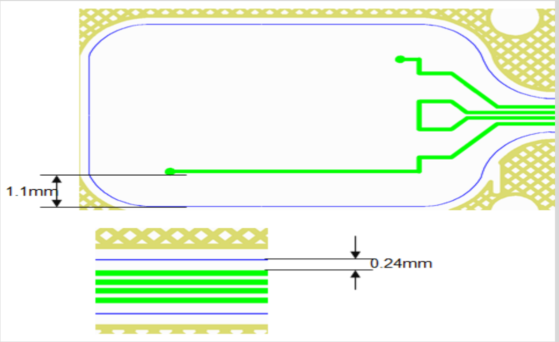
Embedded die with pads on layer (3)

Grid structure on backside (4)

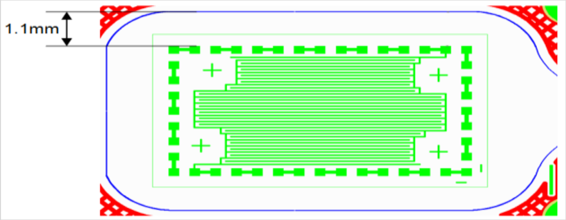




TEST CHIP TO OUTLINE DISTANCES



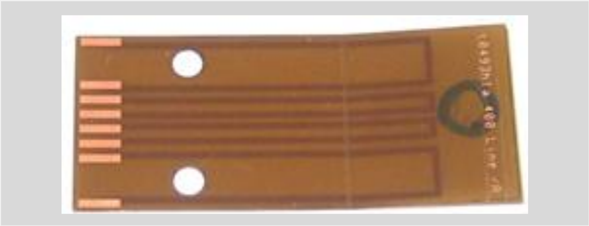
Layer 2 copper / outline distance

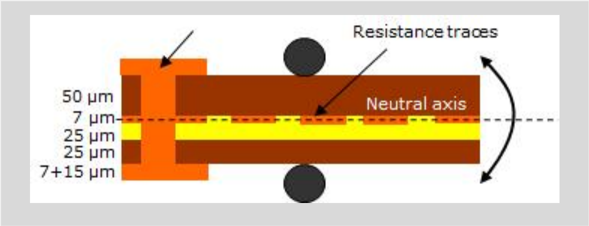


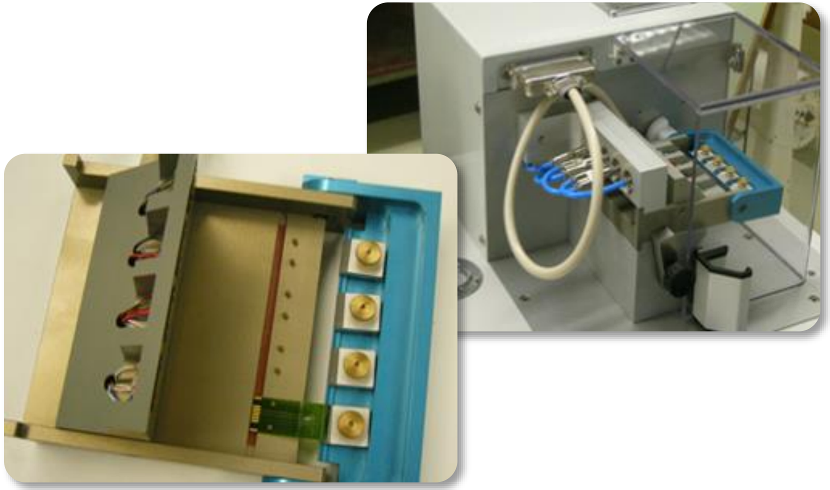
Layer 3 chip artwork / outline distance

BEND TESTING APPARATUS AND METHOD

FIGURE 6



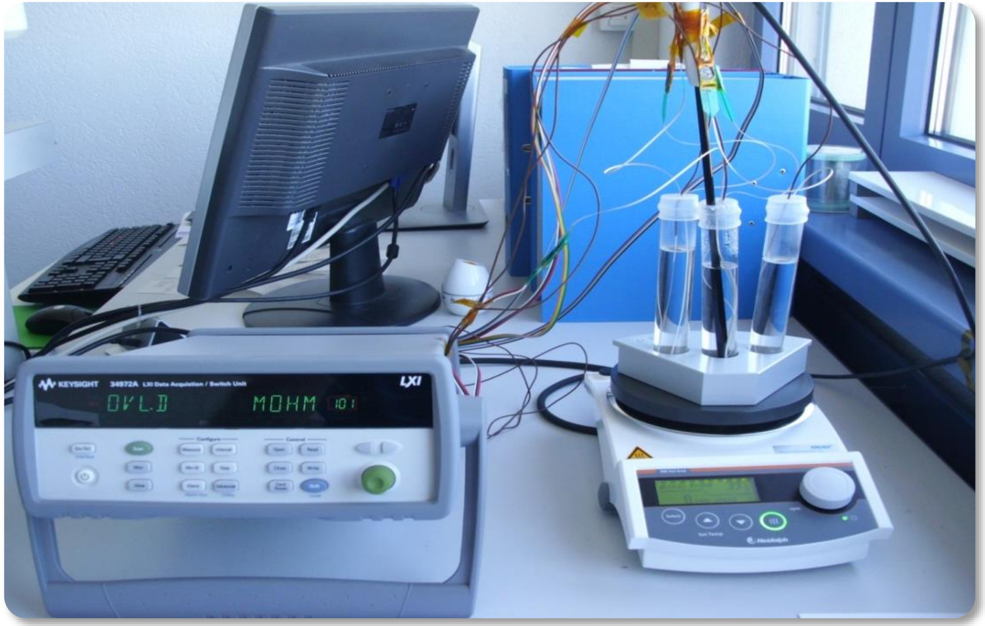




TEST	LCP STRUCTURE	RESULT
Bend (radius 0.5 mm)	LCP with Au traces	**Pass 100k cycles**

SOAK TESTING APPARATUS

FIGURE 7



RESULTS

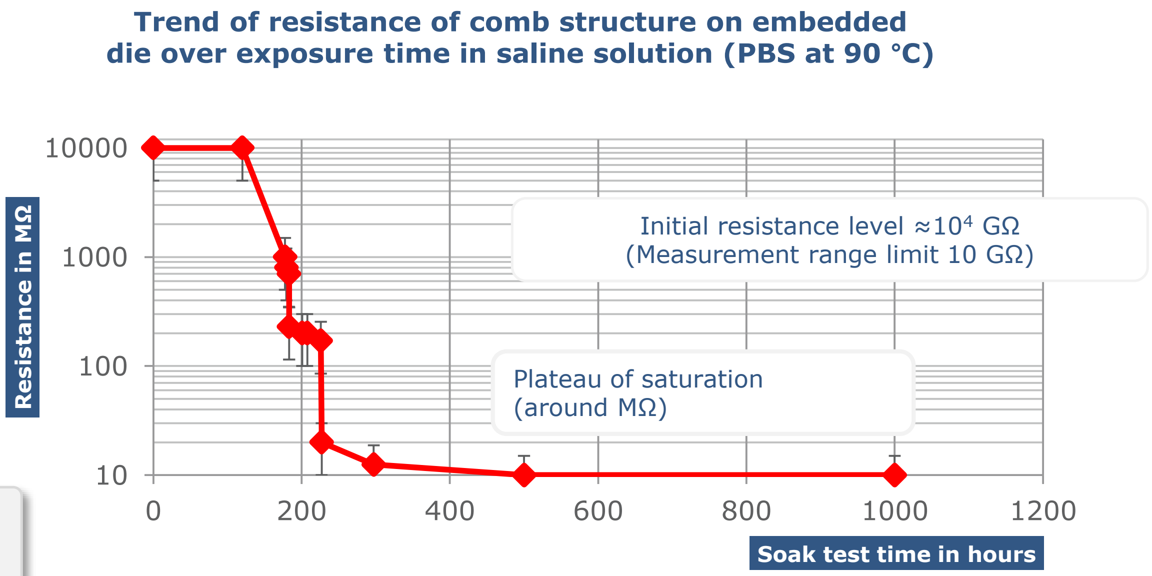
- Noble metal LCP based neural interface and electrode structures successfully fabricated using conventional flex circuit and thin film processing
- **Structures that undergo specialized cleaning operations pass the ISO 10993 cytotoxicity test requirements**
- **LCP structures with Au conductors passed PBS soak testing at 77°C for > 9 months without failure**

PBS SOAK (90°C) TEST RESULTS OF EMBEDDED DIE IN LCP STRUCTURES

SAMPLE	1	2	3	4	5	6	7	8	9	10
Time to value below range limit of 10 GΩ [h]	1'536	1'104	168	840	168	600	384	936	864	336
Saturation Value	> 1GΩ	1.6 MΩ	14 MΩ	0.9 MΩ	21.5 kΩ	2 MΩ	3 kΩ	3 MΩ	5 MΩ	0.2 MΩ

- A resistance reduction was observed in 9 out of 10 samples, occurring between 168 and 864 hours @ 90 °C in PBS
- One sample did not show any reduction of resistance below the range limit of 10 GΩ until 1’536 hours, when the test was terminated

SOAK TEST RESULT



Defect driven migration along interfaces (within approx. 50h)

FAILURE ANALYSIS

- Adhesion between laminated layers was found to be reduced significantly after the soaking test, indicating that moisture penetration is likely the reason for reduced resistance in the comb structure
- Foreign material, which is embedded between the layers, can act as defect side to enhance the moisture migration
- Further work needed to reduce moisture penetration along the interfaces

Evidence of Cu Electromigration

Top layer LCP peeled back on failed electrode structures

RECENT SOAK TEST RESULTS

TEST	LCP STRUCTURE	RESULT
Soak test in PBS at 77° C	LCP with Au traces	> 9 months continuous (equivalent to 15 years implanted in body)
Soak test in PBS at 50° C	LCP with Cu traces, embedded die	Ongoing test (no measureable drop in resistance after >1800 hours)
Soak test in 40% H_2SO_4 at 50° C	LCP with Cu traces, embedded die	Ongoing test (no measureable drop in resistance after >1800 hours)
Soak test in 80% H_2SO_4 at 50° C	LCP with Cu traces, embedded die	Ongoing test (no measureable drop in resistance after >1800 hours)

CONCLUSIONS

- Biocompatible neural interfaces and electrode structures can be fabricated from LCP dielectric and noble metal conductors on conventional flex circuit and thin film manufacturing equipment.

- Passive structures have shown initial feasibility for long term biostability based on PBS soak testing.

- Structures with embedded die show initial promise for biostability, but further process optimization is needed.

- The results demonstrate that a new material set comprised of LCP with noble metals is feasible for producing complex implantable structures for neuromodulation applications.

REFERENCES

[1] J. Jeung, et al., "A novel multilayered planar coil based on biocompatible liquid crystal polymer for chronic pain implantation," *Sensors and Actuators A: Physical*, Volume 197, 1 August 2013, pp. 38-46.

[2] S.W. Lee, et al., "Development of Microelectrode Arrays for Artificial Retinal Implants Using Liquid Crystal Polymers," *IOVS*, December 2009, Vol. 50, No. 12, pp. 5859-5866.

[3] ISO 10993-1:2009 Biological evaluation of medical devices – Part 1: Evaluation and testing with a risk management process.

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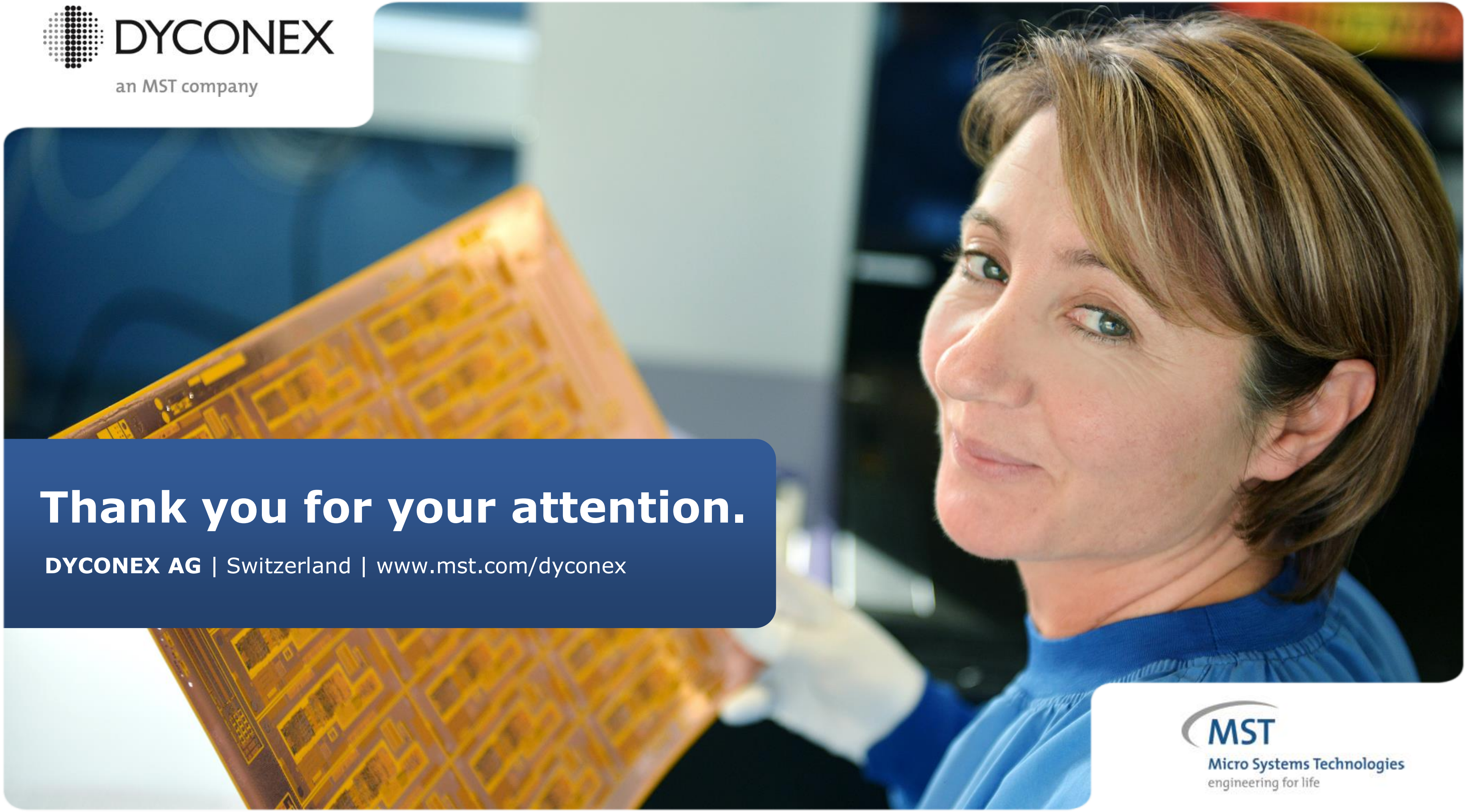

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