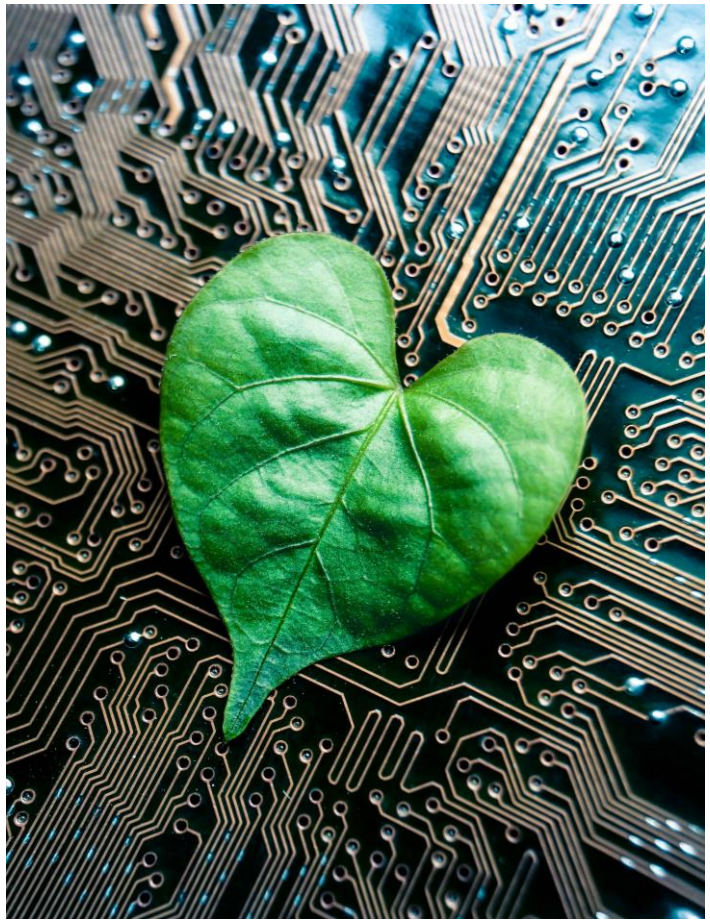

Sustainable printed circuits: a possible path to greener electronics

Attila Géczy, PhD

Habilitated associate professor at BME ETT, HUN

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1) Department of Electronics Technology, Faculty of Electrical Engineering and Informatics, Budapest University of Technology and Economics
2) Meshlin Composites Zrt., Hungary
3) University Grenoble Alpes, Uniersity Savoie Mont Blanc, CNRS, Grenoble INP, IMEP-LAHC, France
4) Department of Energy Engineering, Faculty of Mechanical Engineering, Budapest University.of Technology and Economics
5) Department of Theoretical Physics, Wigner Research Centre for Physics

corresponding email: *geczy.attila@vik.bme.hu*

THE DEPARTMENT:

BMEETT
ELEKTRONIKAI TECHNOLÓGIA TANSZÉK

- Department of Electronics Technology - since 1964

- ***electronic components;***
- ***circuits and systems;***
- ***interconnection and packaging technology of microelectronics + module circuits;***

OUR COMPETENCE FIELDS:

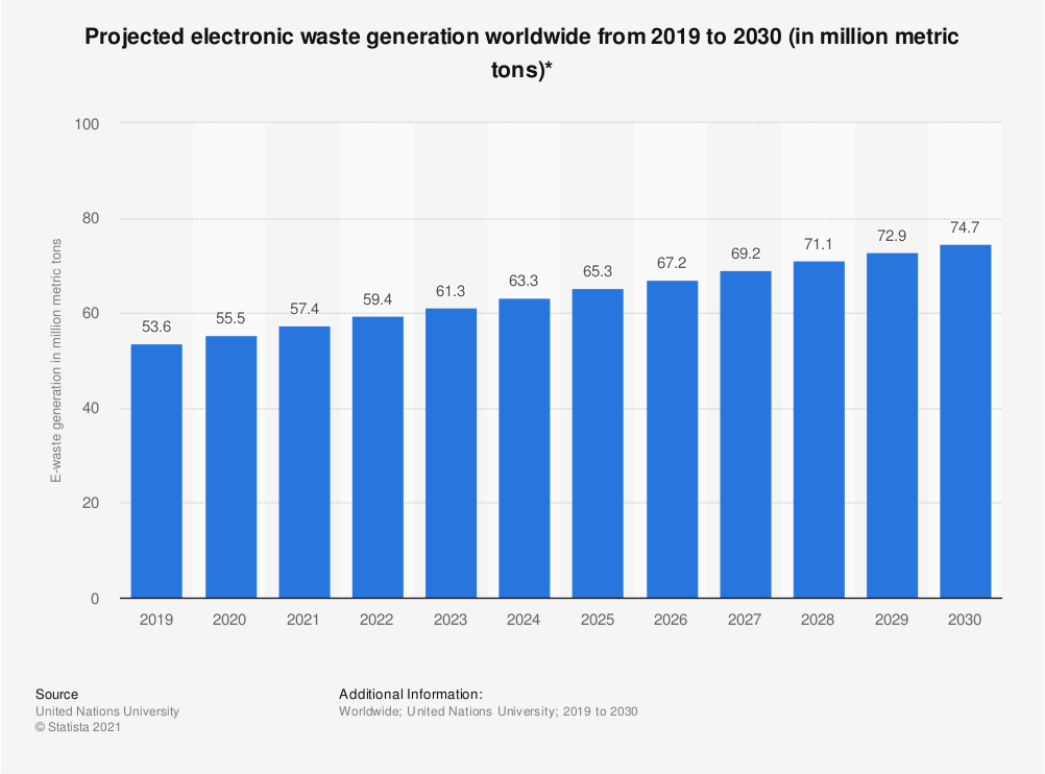
- ***PCB and circuit design & manufacturing;***
- ***CAD, modelling, simulations;***
- ***Assembly technologies: SMT, THT;***
- ***Failure investigation;***
- ***Biosensors and nanometrology;***
- ***Lasers; Thick & Thin Films;***
- ***Applied sensors;***

WE CONNECT CHIPS AND SYSTEMS

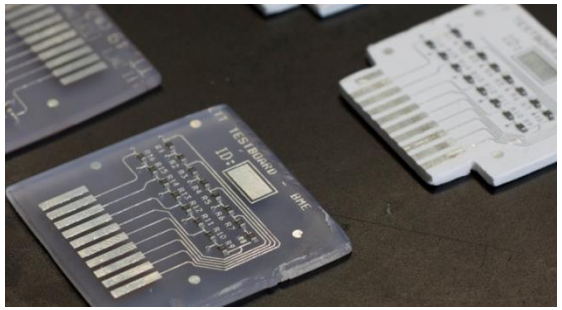
OUR PATH TO GREENER ELECTRONICS

Electronic waste / Cellulose acetate pellets

- ***Trend:*** E-waste concerns, circular economy…
- ***Biobased-boards:*** possible path for greener electronics;



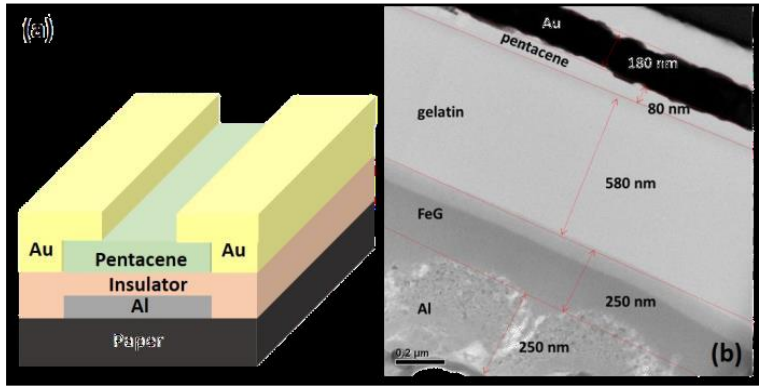
PCBs – subtractive technology:



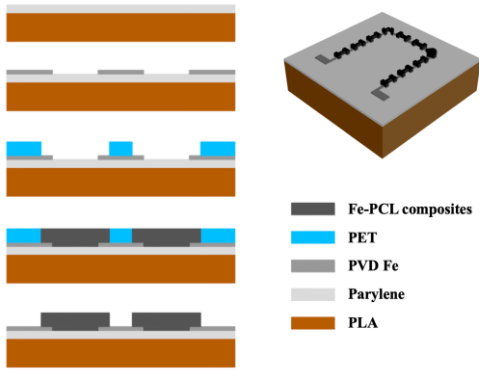
- Department of Electronics Tech. – active research field since 2009.
- Biodegradable PCBs with standard assembling tech.
- Possible commercial application **identification, throwables, commercial electronics.**

WE CONNECT CHIPS AND SYSTEMS

GREEN ELECTRONICS IN LITERATURE



Biodegradable Materials for Organic Field-effect Transistors on a Paper Substrate, Lee et al. 2019



iron-polycaprolactone

Electrical Interconnects Fabricated From Biodegradable Conductive Polymer Composites, Zhang et al. 2019.

Bioplastics can be considered as a polymer class.

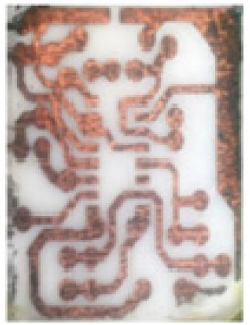
Sub-classes are:

- Biodegradable or compostable but not bio-based (synthetic)
- Biodegradable or compostable and bio-based
- Non-biodegradable but bio-based

Plant-Based Completely Biodegradable Printed Circuit Boards, Guna et al. 2016.

Banana fibers,
Wheat gluten.

Usability of Bio-based Polymers for PCB, Hanning et al. 2019.



A.Yedrissov, D. Khrustalev, A. Alekseev, A. Khristaleva, A. Vetrova „New composite material for biodegradable electronics" Materials Today

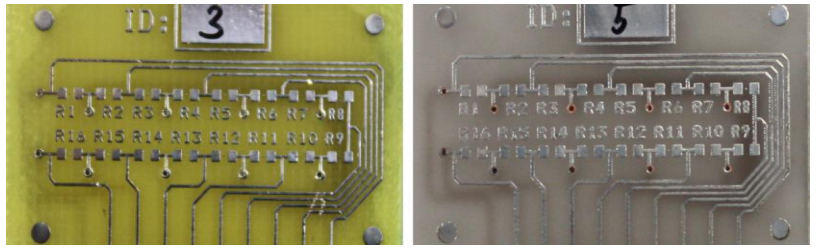
WE CONNECT CHIPS AND SYSTEMS

PREVIOUS PROJECTS (BIO PCBs)

EXAMPLES FROM THE VAULTS OF OUR DEPT:

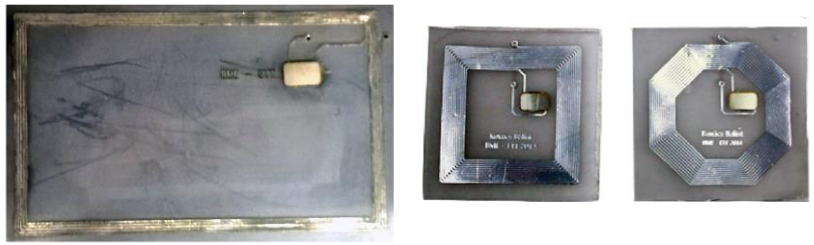
PLA, CA, GPTE

Test circuits made of PLA and CA materials
Focus on low temp. Soldering.



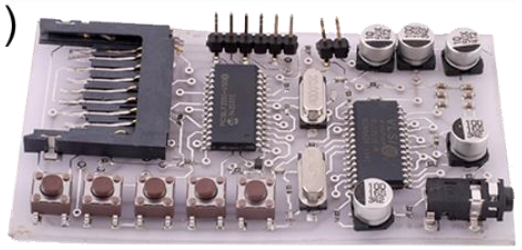
Subtractive technology

APPLICATION



RFID Application with custom made designs

b.)



MP3 player prepared on biodegradable CA substrate

WE CONNECT CHIPS AND SYSTEMS

NOVEL SUBSTRATE

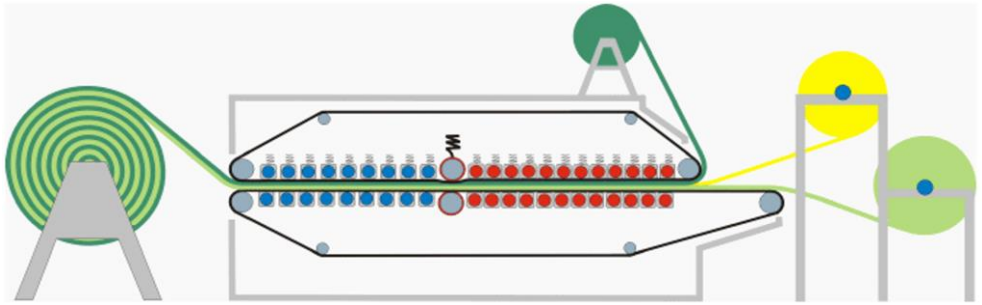
- Continuing the subtractive technology research;
- Applying a new material for surface mounting;
- Reinforced + Flame Retarded!

GREEN LAMINATE PRODUCTION

SUBTRACTIVE PCB FAB

PCB ASSEMBLY (SM)

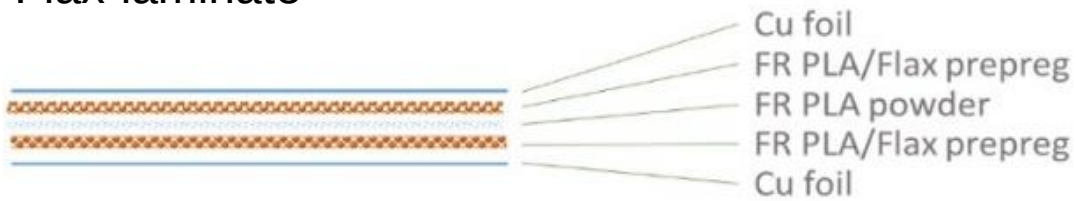
Reliant's Powerbond-HPC



meshlin

MESHINING Engineering

Flax-laminate

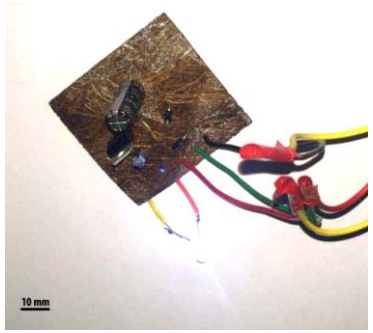


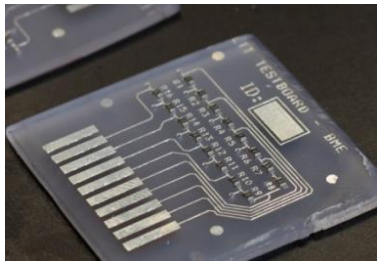
Compatiblilty with traditional processes.

MOTIVATION IDEA

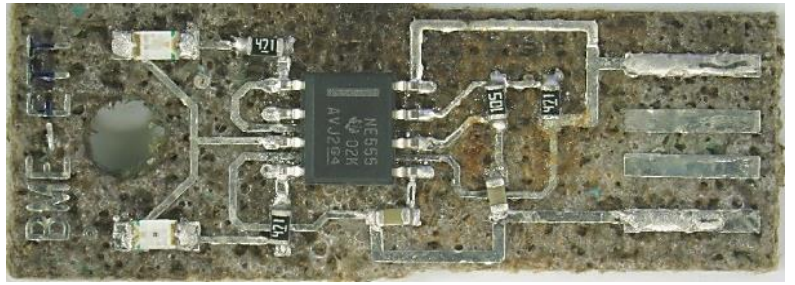
- Currently:

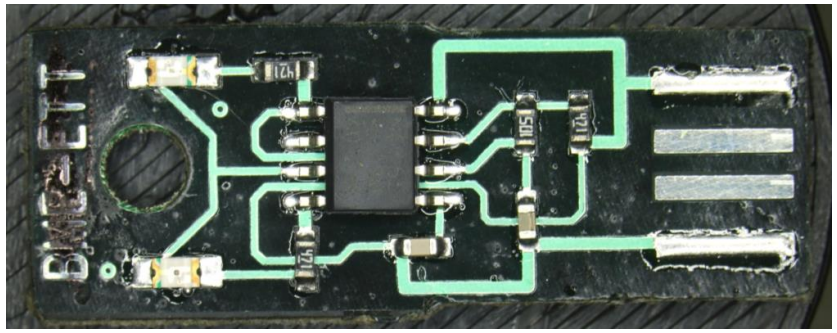
Literature examples

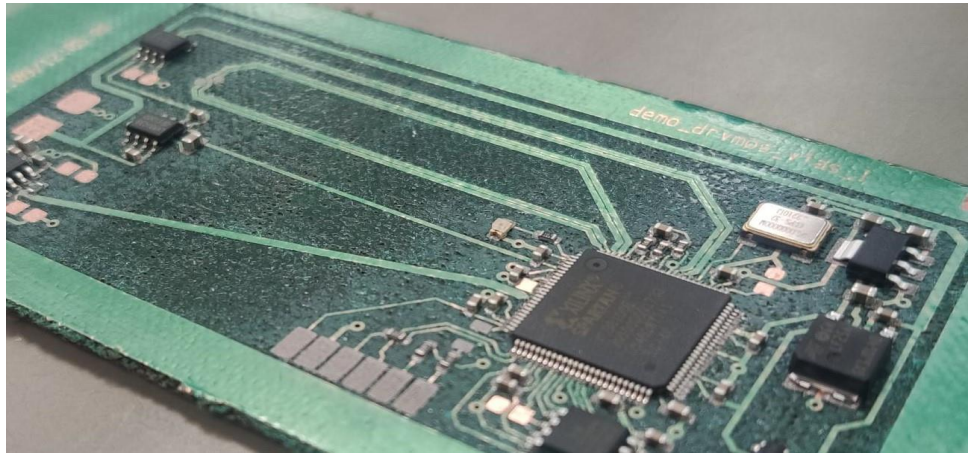




Where are we at the moment?

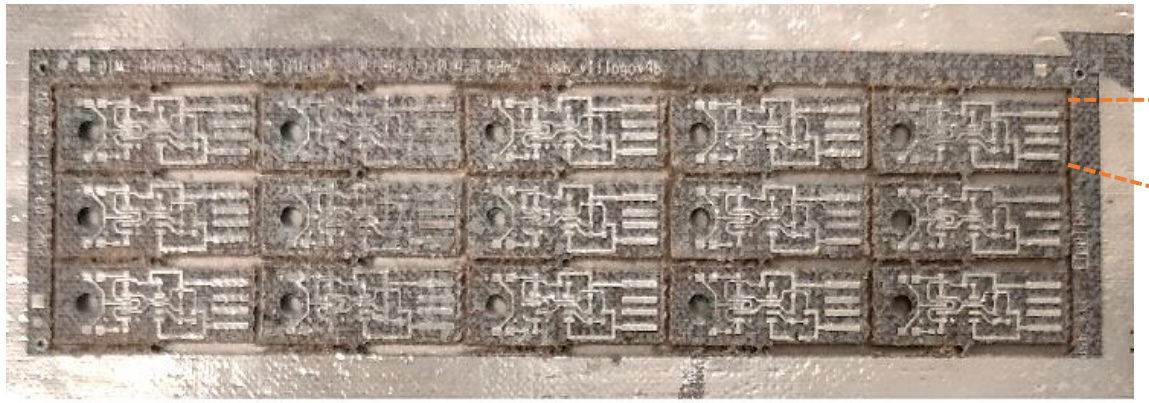






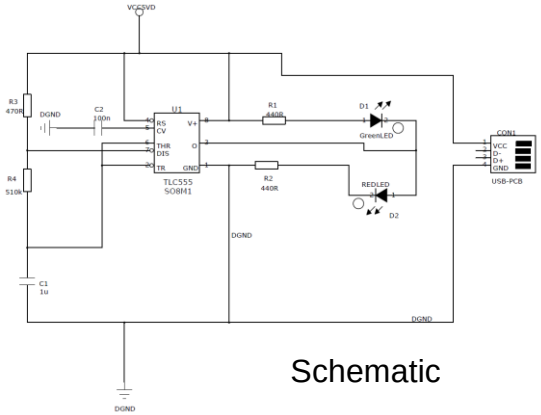
WE CONNECT CHIPS AND SYSTEMS

FIRST GENERATION

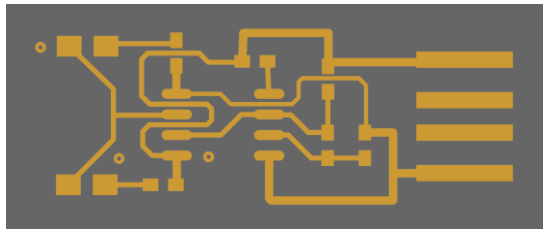


„Blinker circuit” – mounted on a frame (15 pcs)

Cross section of prepared sample, 2 mm
35 microns of Cu layers.
Prepared for **subtractive technology.**



Schematic

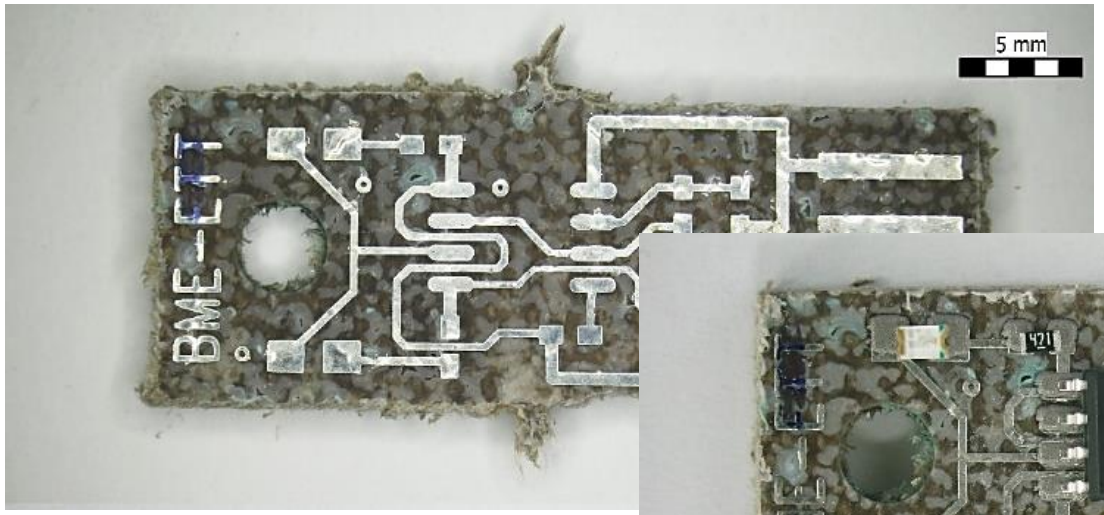


Layout

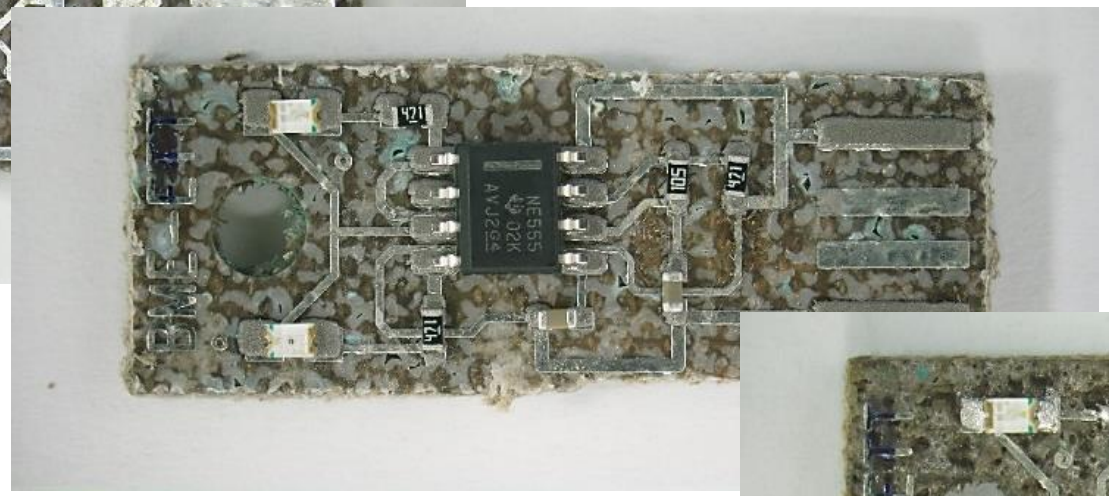
- Simple demonstration.
- USB mountable.
- 2 mm tickness / one sided design.
- SOIC, 0603 SMD components.

WE CONNECT CHIPS AND SYSTEMS

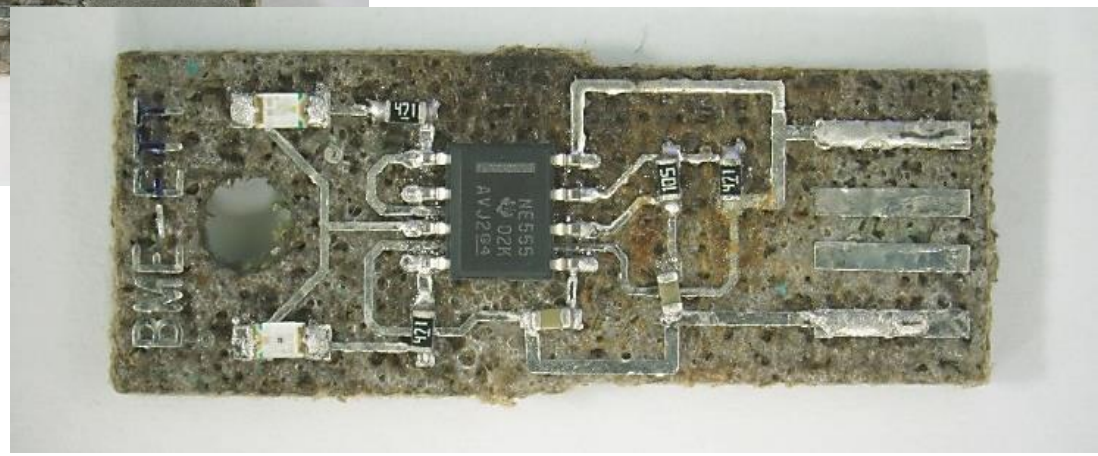
SMD STEPS



1. Preparation for stencil printing



2. Surface mounting onto paste



3. Reflow in vapour phase oven.

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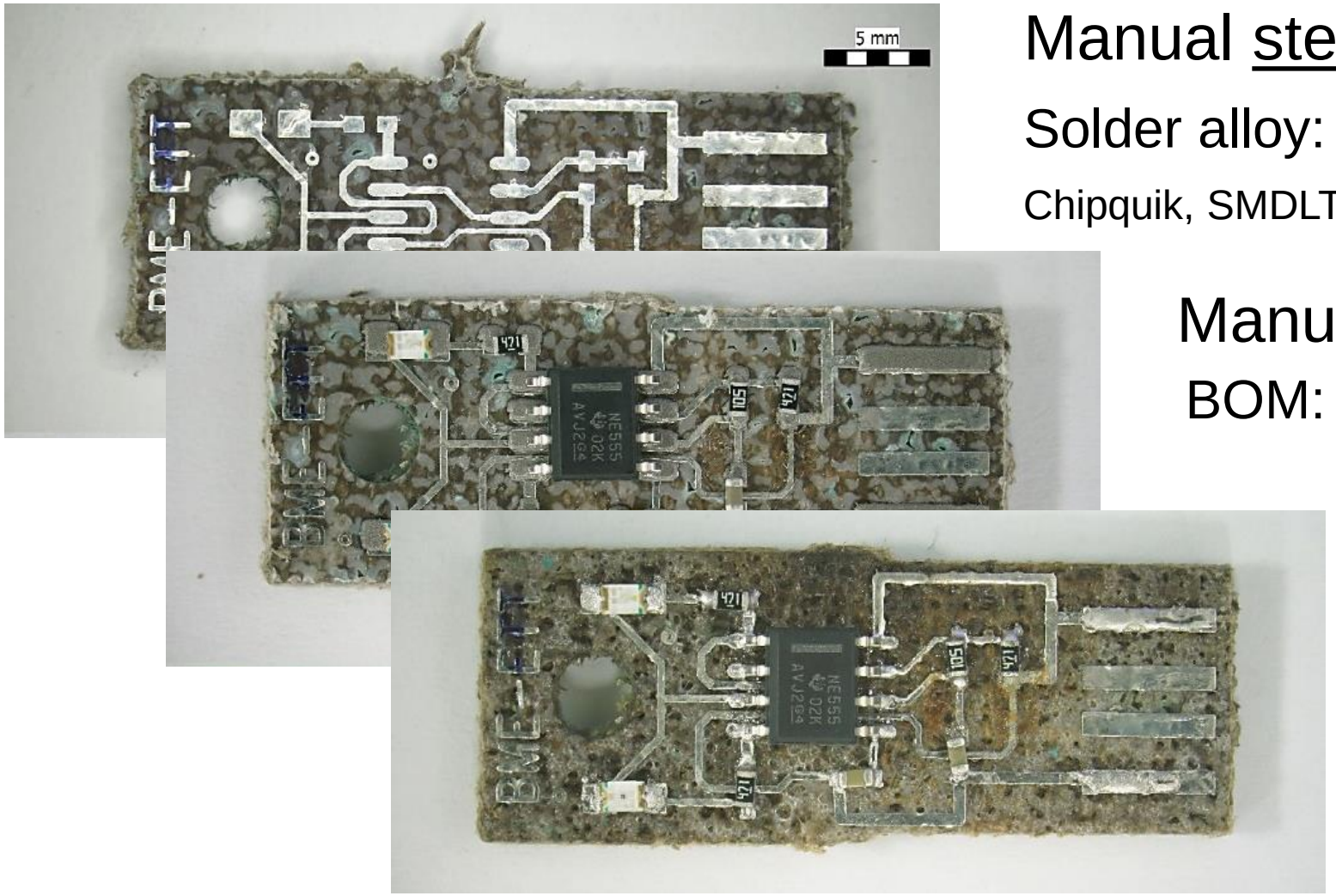
SMD PARAMETERS

LEAD FREE



Manual <u>stencil printing</u>.

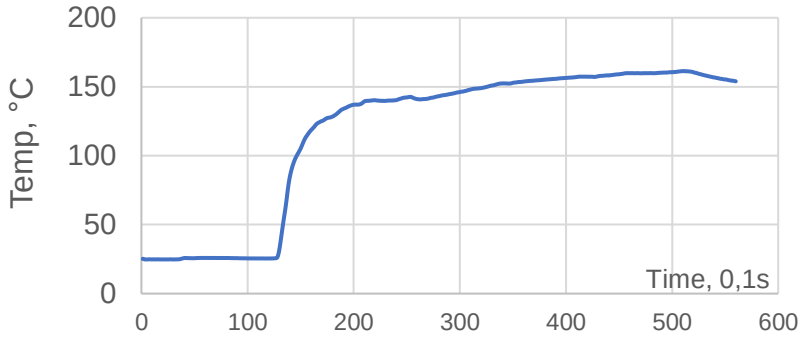
Solder alloy: SN42/**BI57.6**/AG0.4

Chipquik, SMDLTLFP60T4, **T_m: 138°C**.

Manual <u>pick and place</u>.

BOM: according to design.

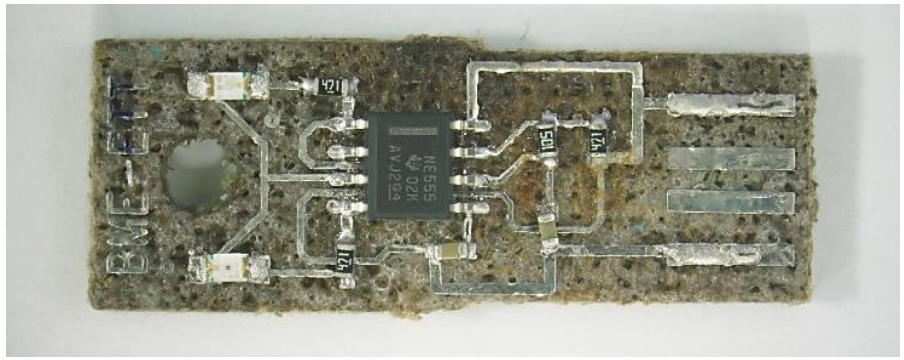
Vapour Phase <u>Reflow</u> (170°C)



WE CONNECT CHIPS AND SYSTEMS

EXPERIMENTAL – METHODS OF VALIDATION

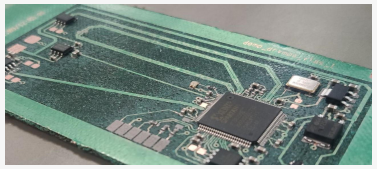
EXPERIMENTAL



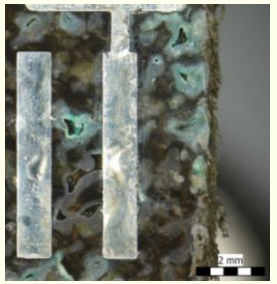
PEELING TEST

IPC-TM-650

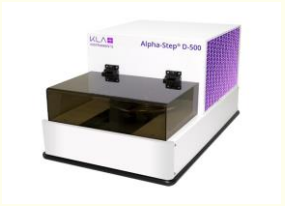
RF CHARACTERIZATION



SURFACE ROUGHNESS



Alpha-step 500



MASS INCREASE

A&D HM-300

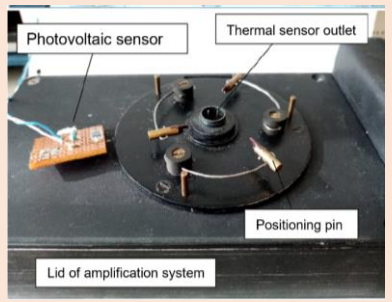
Sub-µg precision

SHEAR STRENGTH

0603 components

Dage 2400

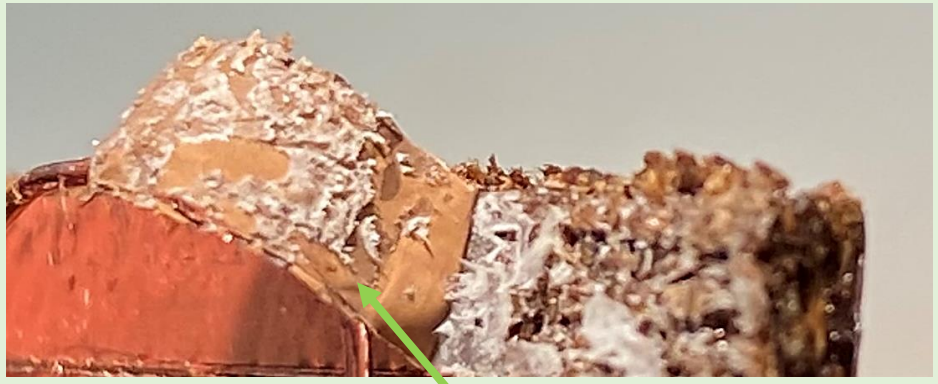
THERMAL CHARACTERIZATION



Flash method Thermal diffusivity

WE CONNECT CHIPS AND SYSTEMS

PEELING TEST

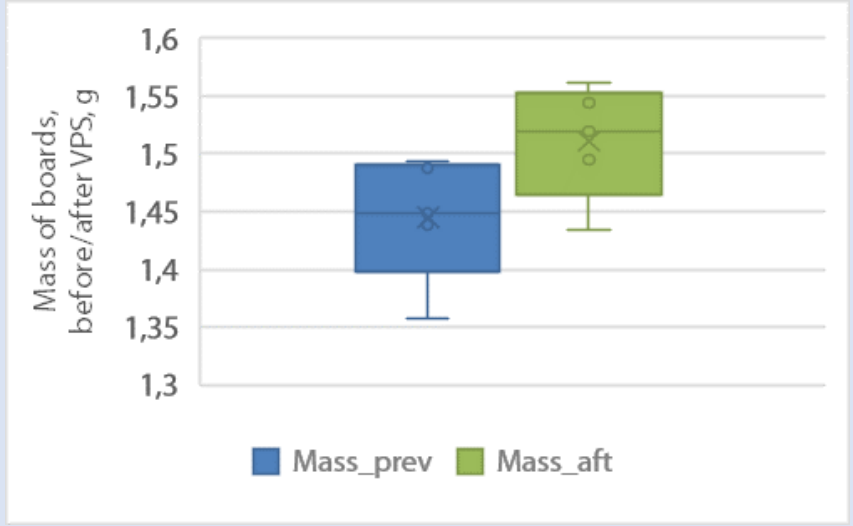


IPC-TM-650

Boards	Measured range N/3,2 mm	Mean N/mm
Laminated board 1	1,60-3,40	**0,78**
Laminated board 2	1,70-1,86	**0,56**
Soldered board 1	1,75-1,90	**0,58**
Soldered board 2	1,85-2,10	**0,62**

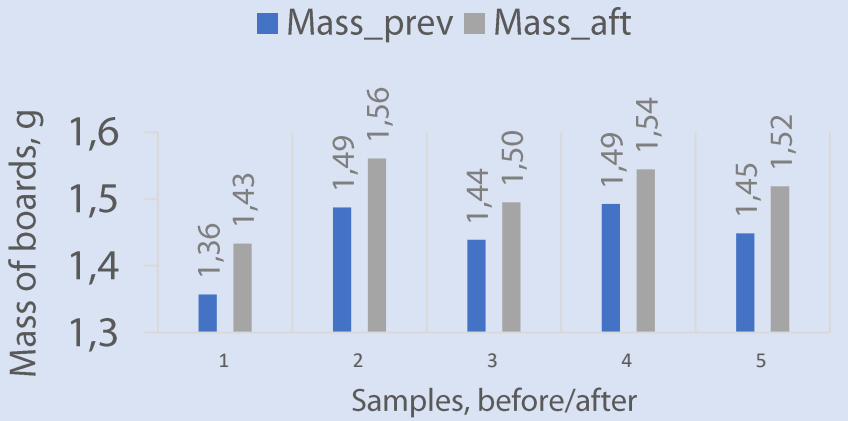
IPC RECOMMENDS: **1,4 N/mm**

MASS INCREASE



~ 0,06 g increase **(4-5%)**

Galden fluid of vapour phase soldering seeps within the weaves, increasing the overall mass.



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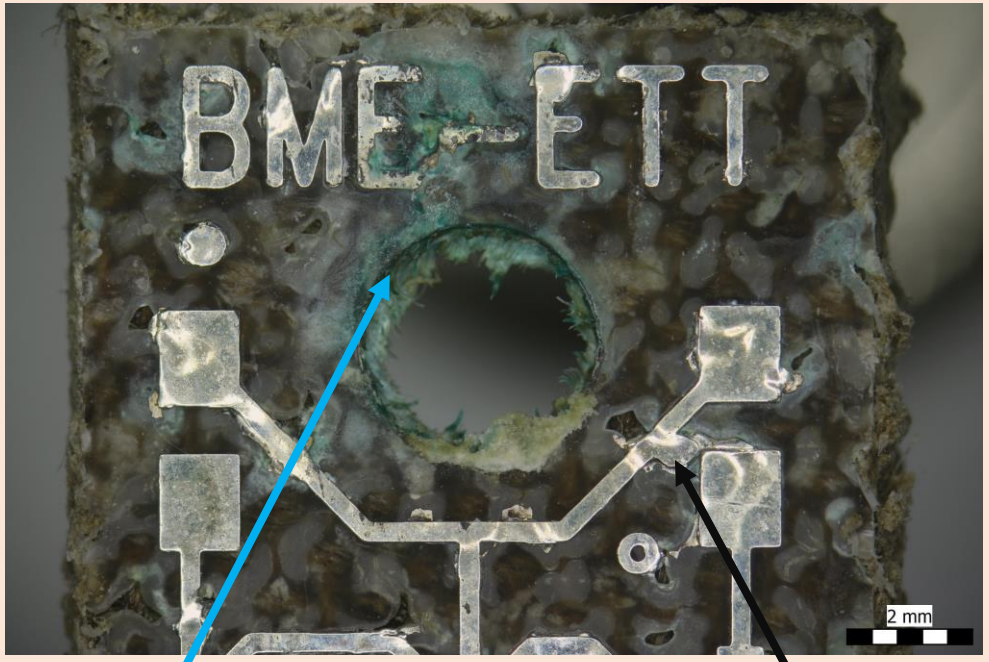
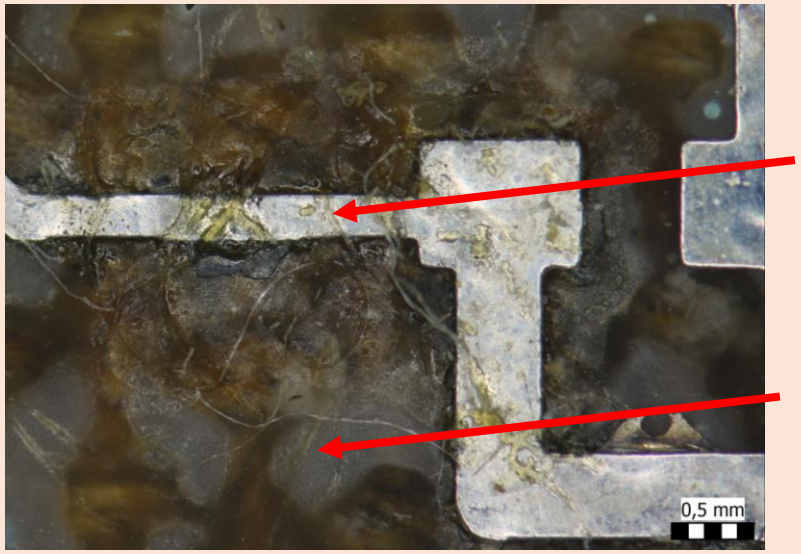
TYPICAL FAILURES



SEEPING ELECTROLYTES

INCONSISTENT COPPER CONTOURS SHORTS



INCONSISTENT PLA SURFACE

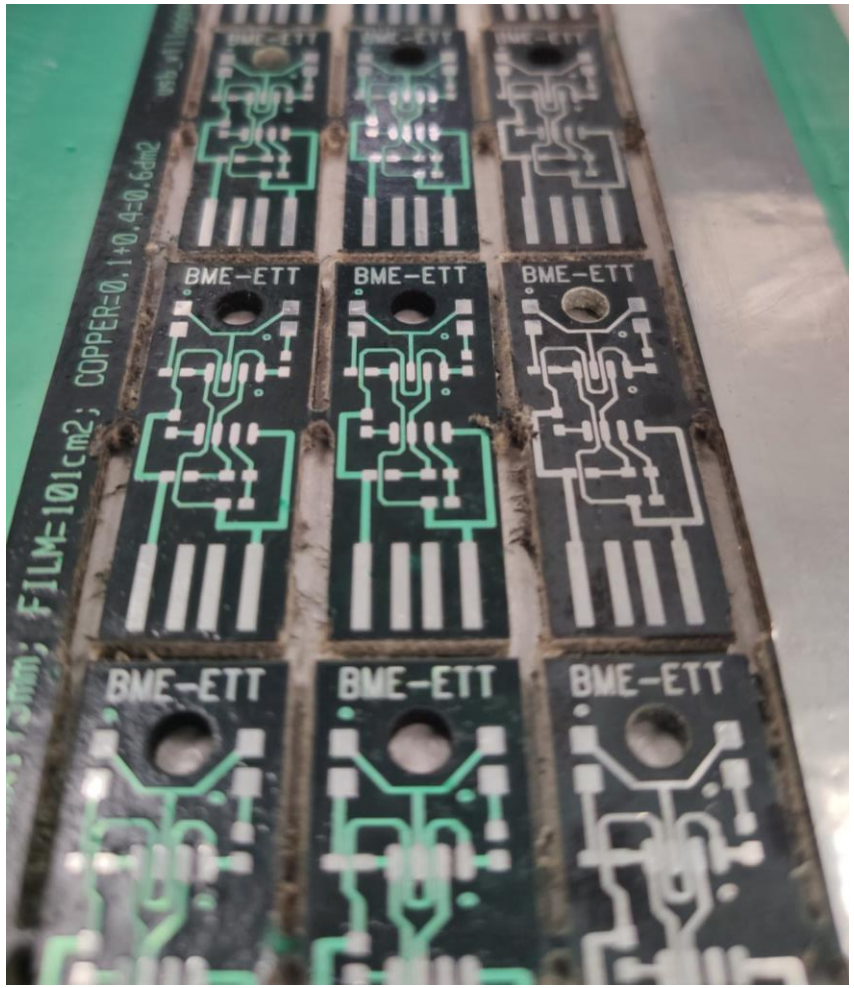
PLA „BUBBLES” BETWEEN SURFACE AND WEAVES

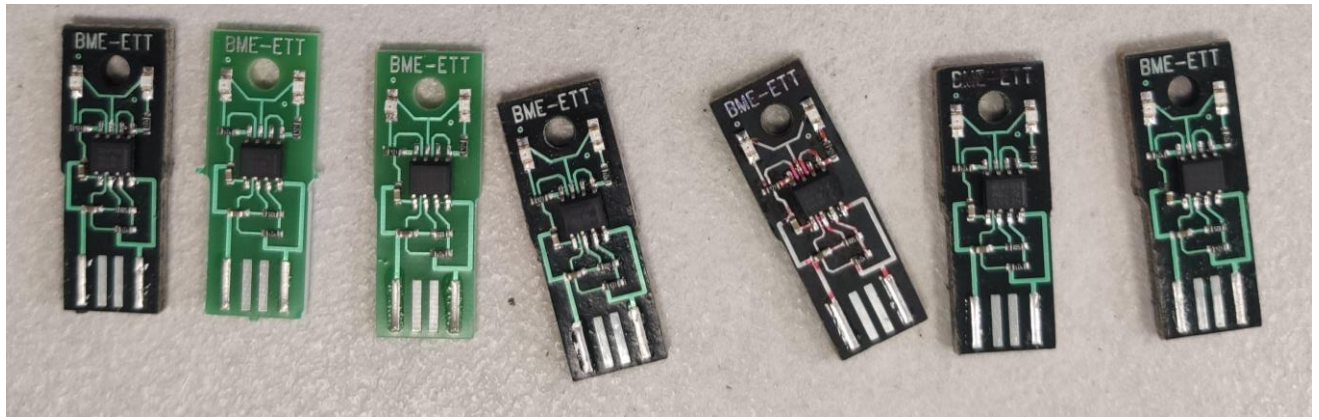
BURST PLA „BUBBLES”

UNEVEN SURFACE!

WE CONNECT CHIPS AND SYSTEMS

2ND GEN FLAX BOARDS - IMPROVEMENTS





IN 2 MONTHS!

SECOND GENERATION:

- IMPROVED PLA/FLAX STRUCTURE
- IMPROVED SURFACE ROUGHNESS
- IMPROVED COPPER & PLA EVENNESS
- WITH AND WITHOUT SOLDER MASK
- IMPREGNATED WEAVES (COMPATIBILITY)

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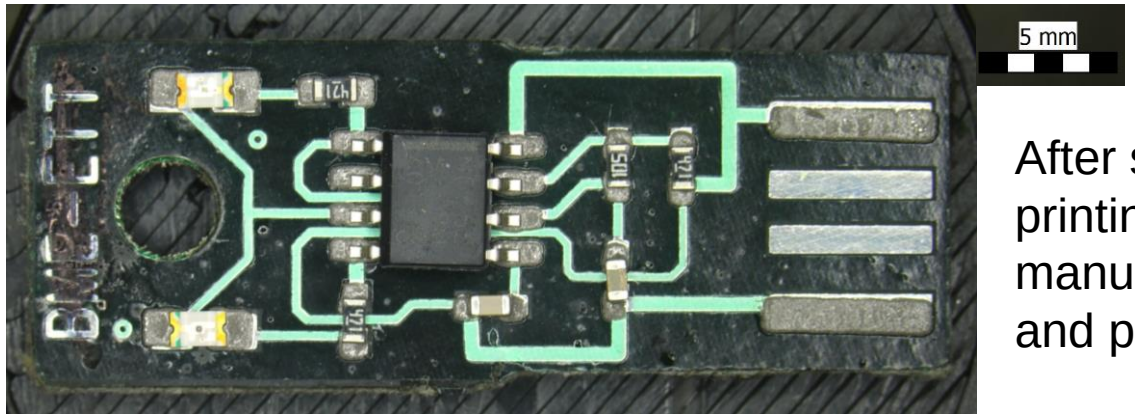
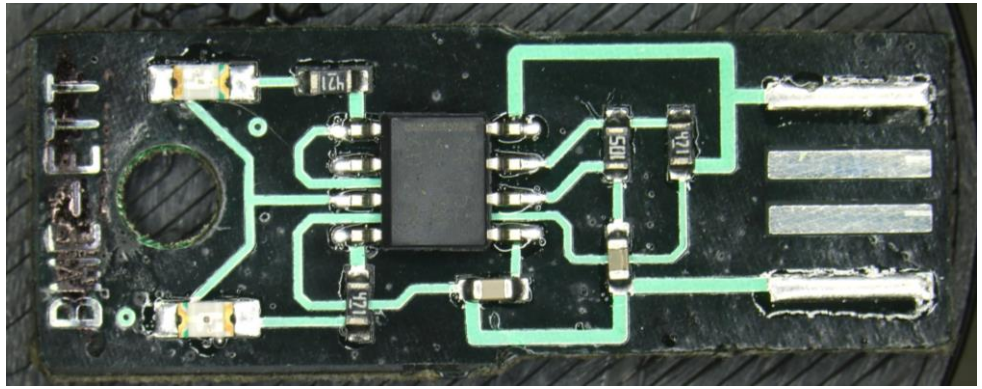
2ND GEN FLAX BOARDS - RESULTS

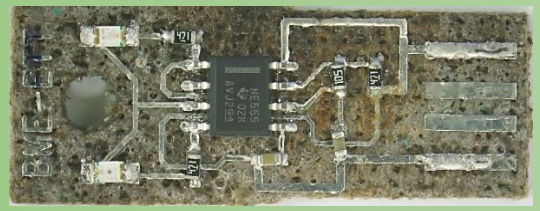


After stencil printing and manual pick and place.

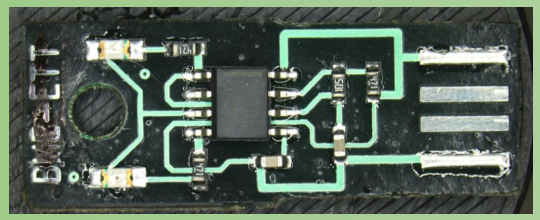


After reflow soldering in vapours.

YIELD IMPROVEMENT



GEN1:
1/10 working.



GEN2:
10/10 working.

10% -> 100% improvement!

AVOIDED: SOLDER BALLING, SHORT CIRCUITS, EXCESSIVE TOMBSTONING.

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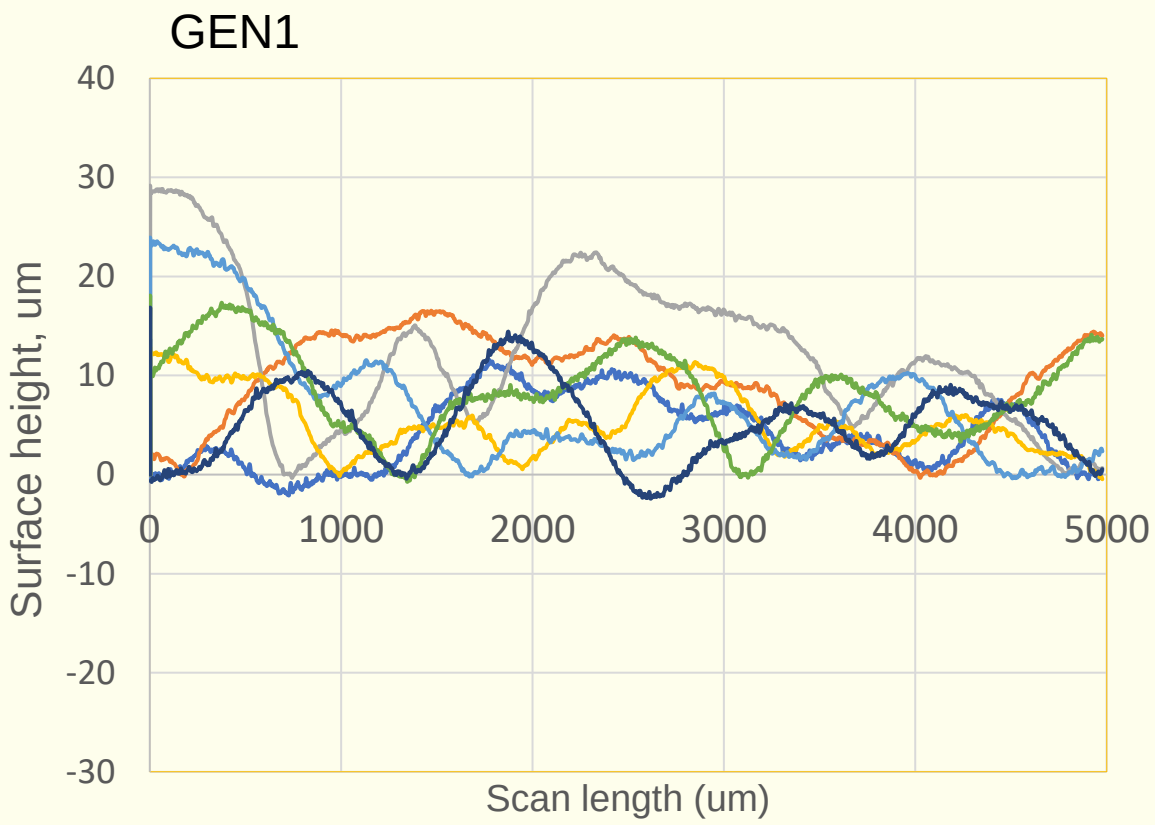
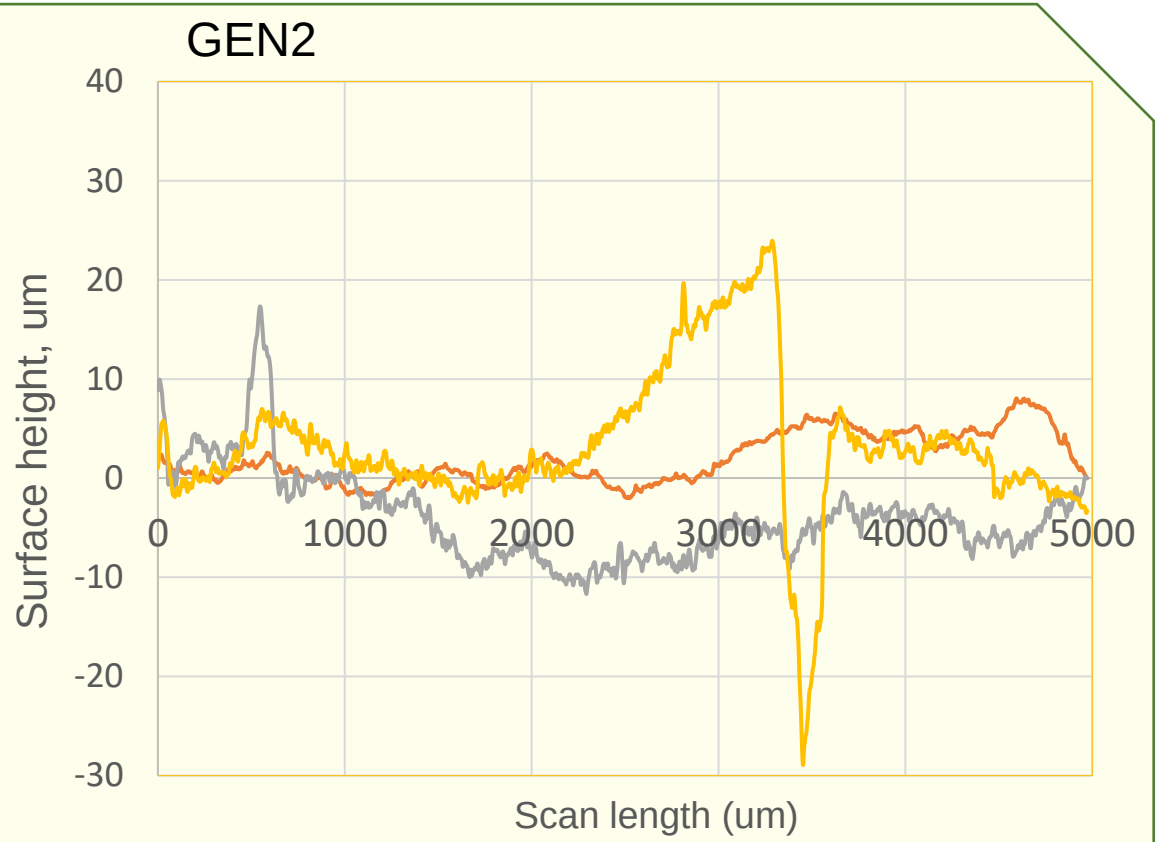
SURFACE ROUGHNESS GEN1 vs GEN2





R_a avg = 8,77
R_t avg = 19,38

Scanning length = 5 mm

R_a avg = 5,77
R_t avg = 16,44

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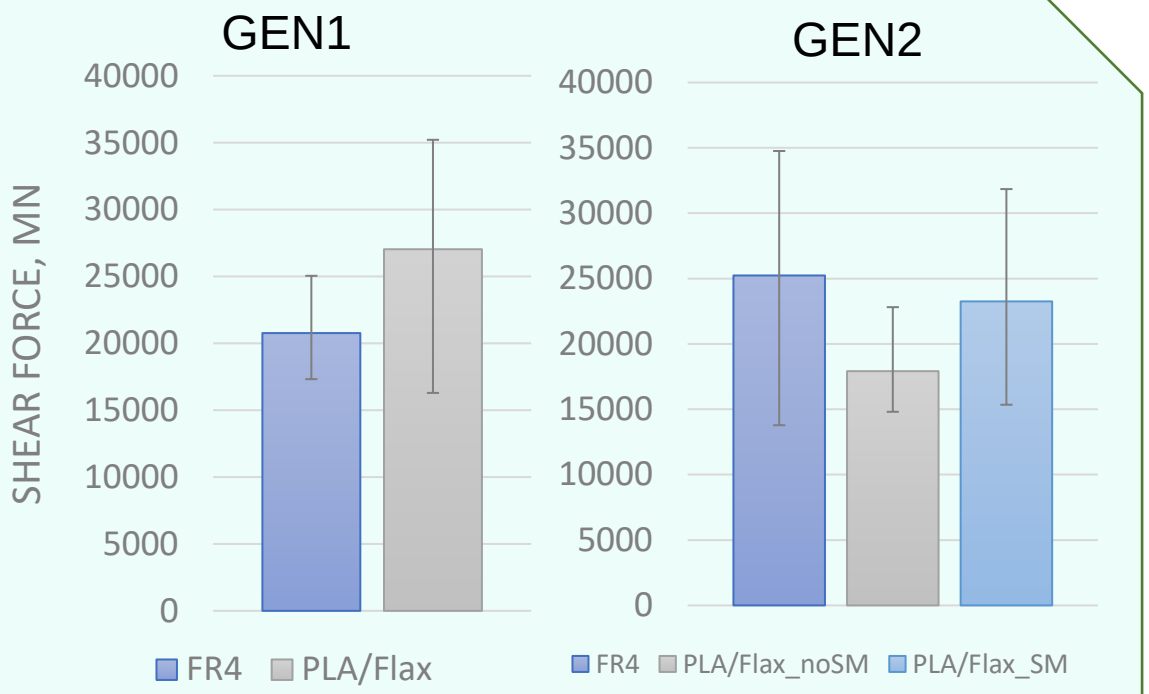
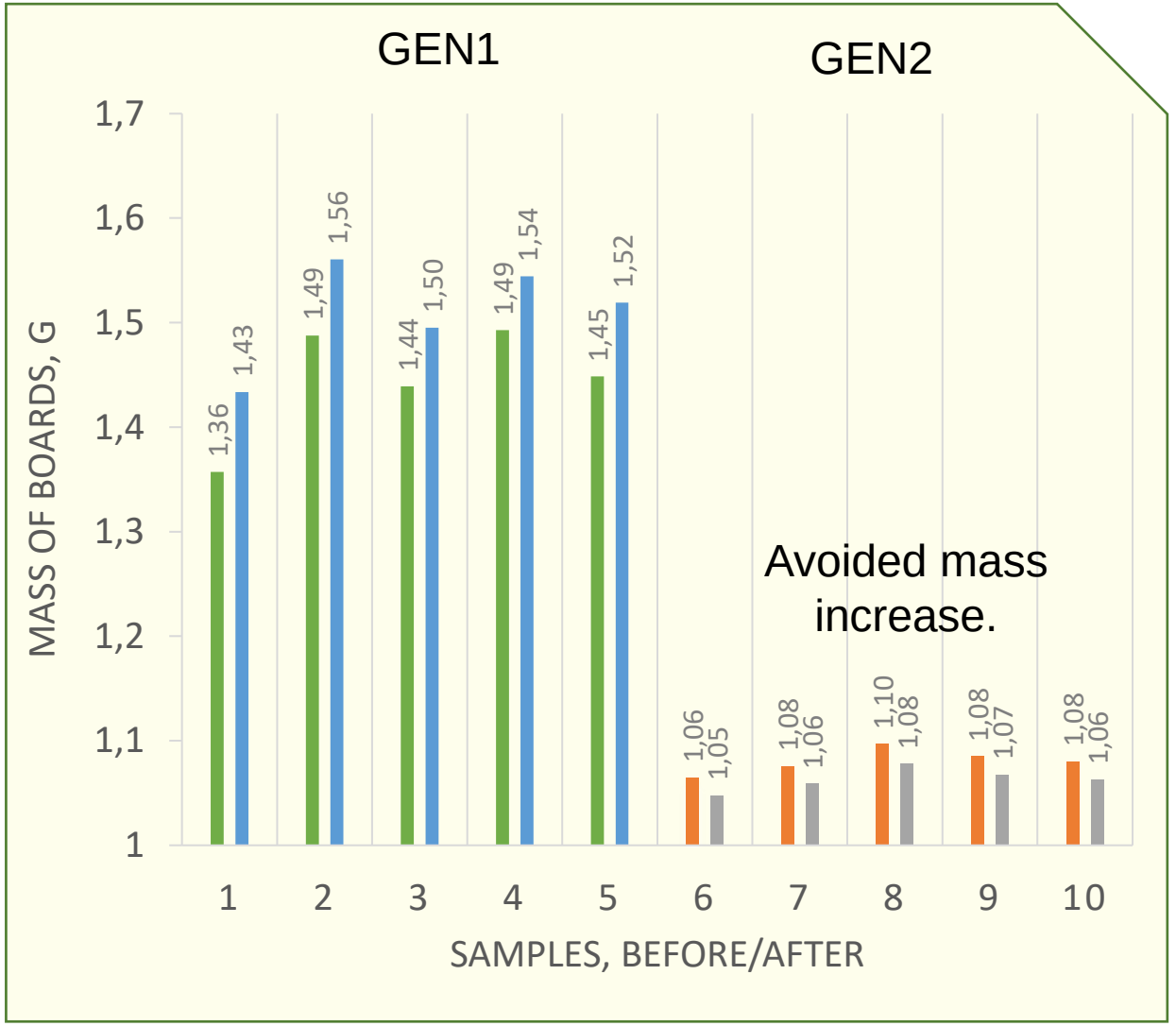
SHEAR & MASS – GEN1 vs GEN2



Cracked joints were found to be better on PLA.

Only pad lifted joints on PLA (either noSM or SM)

SM : SOLDER MASK



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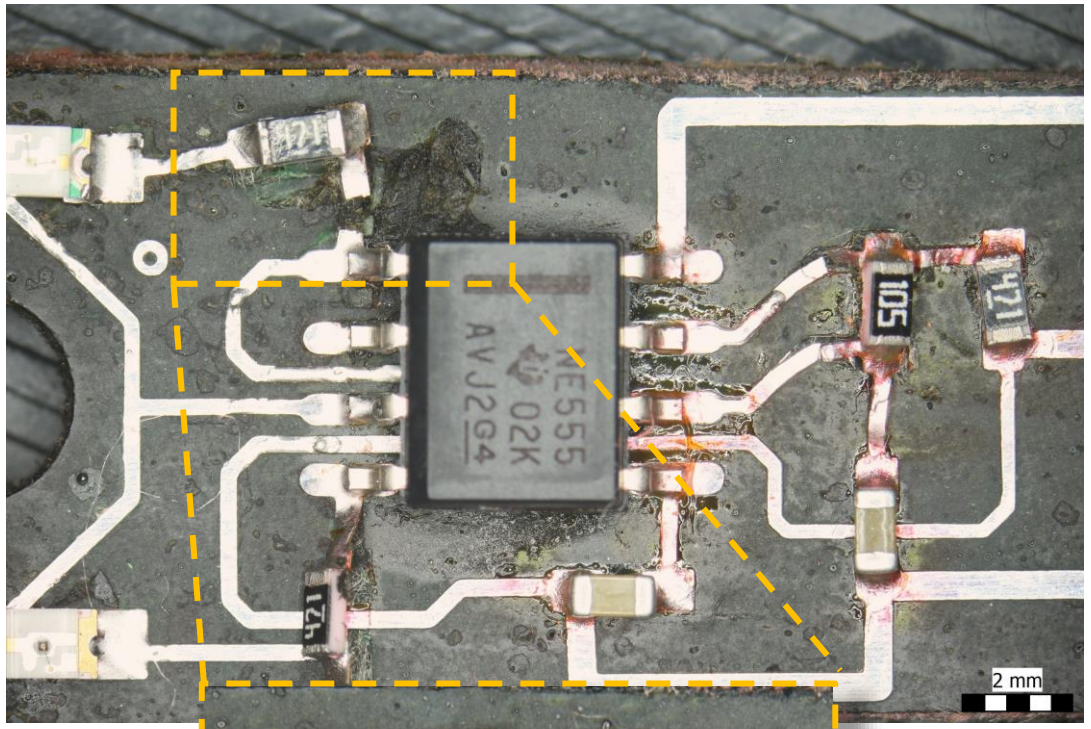
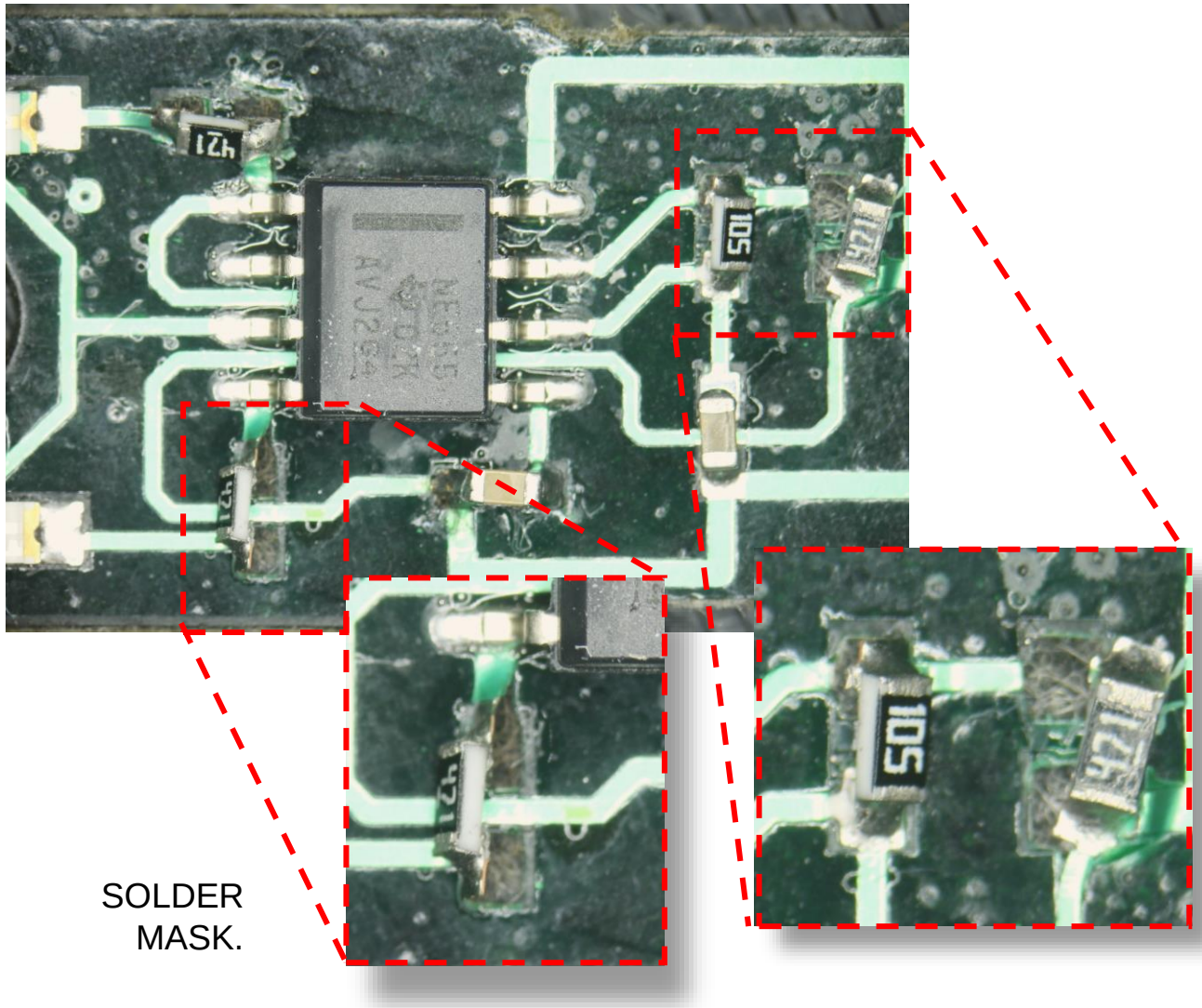
SHEAR TEST EXAMPLES – GEN2



NO SOLDER MASK.

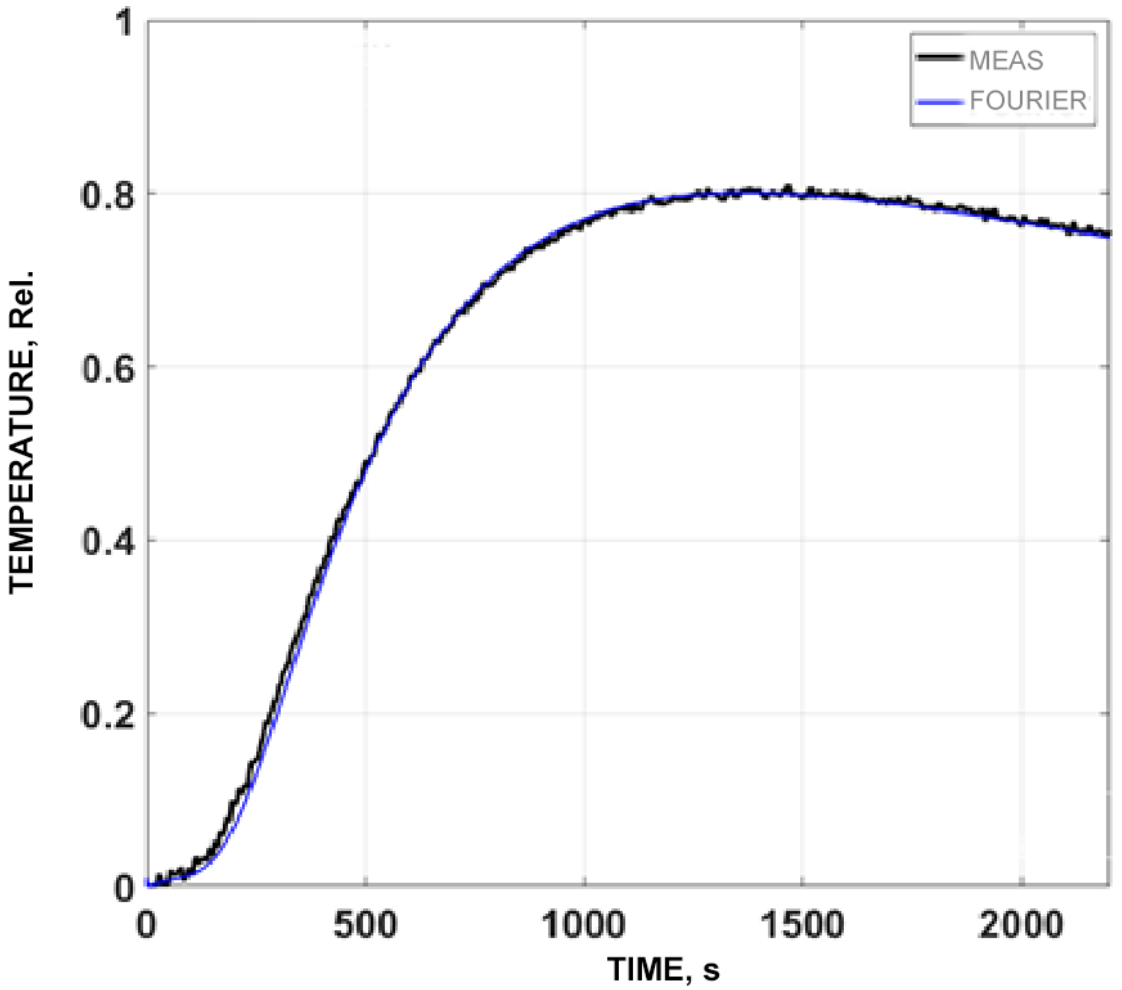


SOLDER MASK.

WE CONNECT CHIPS AND SYSTEMS

THERMAL CHARACTERIZATION

- Fourier-plot fitted considerably well. (This equation typically gives an accurate approximation for homogeneous materials.)
- The material we measured was not homogeneous, *yet the model approximates it appropriately with a* ***similarity to the thermal diffusivity of bulk PLA materials***.
- We obtained an average value of **5.65·10 8 m2/s** (from seven measurements)



RF CHARACTERIZATION + LCA

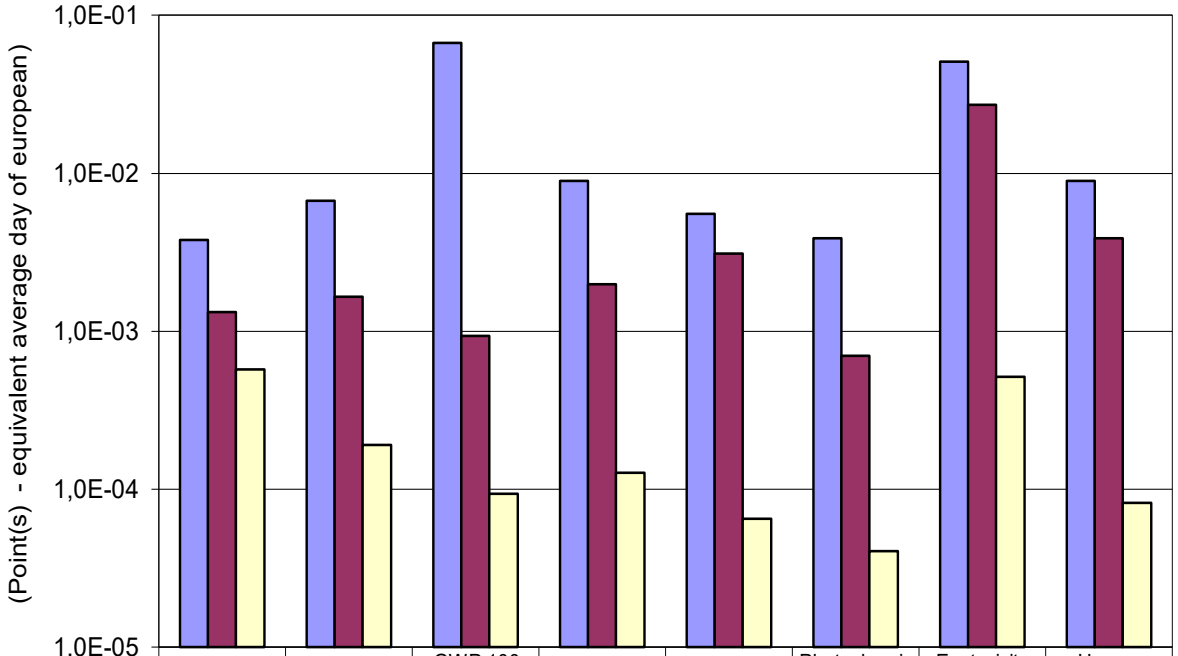
GOOD COMPROMISE!

RF-losses of paper and PLA/Flax based substrates (5% error)

Material	Thickness(µm)	Frequency(GHz)	eps'	Tan(delta)
Paper	128	0,93	3,28±0,04	0,122±0,008
Paper	128	2,48	2,92±0,02	0,101±0,003
Paper	128	4,3	3,2 *	0,1 *
Paper	128	4,7	3,1 *	0,1 *
Paper	128	8,3	3,1 *	0,09 *
Paper	128	10,3	3 *	0,09 *
PLA	1300	0,93	2,49±0,17	0,05±0,01
PLA	1600	2,48	2,31±0,16	0,04±0,01
PLA	800	55	3 *	0,02 *
PLA	800	65	3 *	0,03 *
PLA	1250	55	2 *	0,015 *
PLA	1250	65	2 *	0,08 *
PLA	1500	55	2,2 *	0,02 *
PLA	1500	65	2,2 *	0,03 *

- TanDelta: 5 times lower than in paper-based substrates due to the moisture content of the papers, and of the same order of magnitude as in FR4 substrates.
- **With optimization: traditional substrates can be approached!**

Wi-Fi Antenna classification from environmental aspect



	Energy NR (MJ eq)	Resources (kg Sb eq)	GWP 100 mod (kg CO2 eq)	Acidification (kg SO2 eq)	Eutrophis. (kg PO4- eq)	Photochemical poll. (kg C2H4)	Ecotoxicity (kg 1,4-DB eq)	Human toxicity (kg 1,4-DB eq)
Rogers	3,8E-03	6,7E-03	6,7E-02	9,0E-03	5,5E-03	3,9E-03	5,1E-02	8,9E-03
PLA	1,3E-03	1,7E-03	9,3E-04	2,0E-03	3,1E-03	7,0E-04	2,7E-02	3,9E-03
Paper	5,8E-04	1,9E-04	9,4E-05	1,3E-04	6,5E-05	4,1E-05	5,1E-04	8,2E-05

Thermal and RF Characterization of Novel PLA/Flax Based Biodegradable Printed Circuit Boards Attila Géczy, András Csiszár, Pascal Xavier, Nicolas Corrao, Dominique Rauly, Róbert Kovács, Anna Éva Fehér, Egon Rozs, László Gál, 2022 IEEE 24th Electronics Packaging Technology Conference (EPTC) Singapore.

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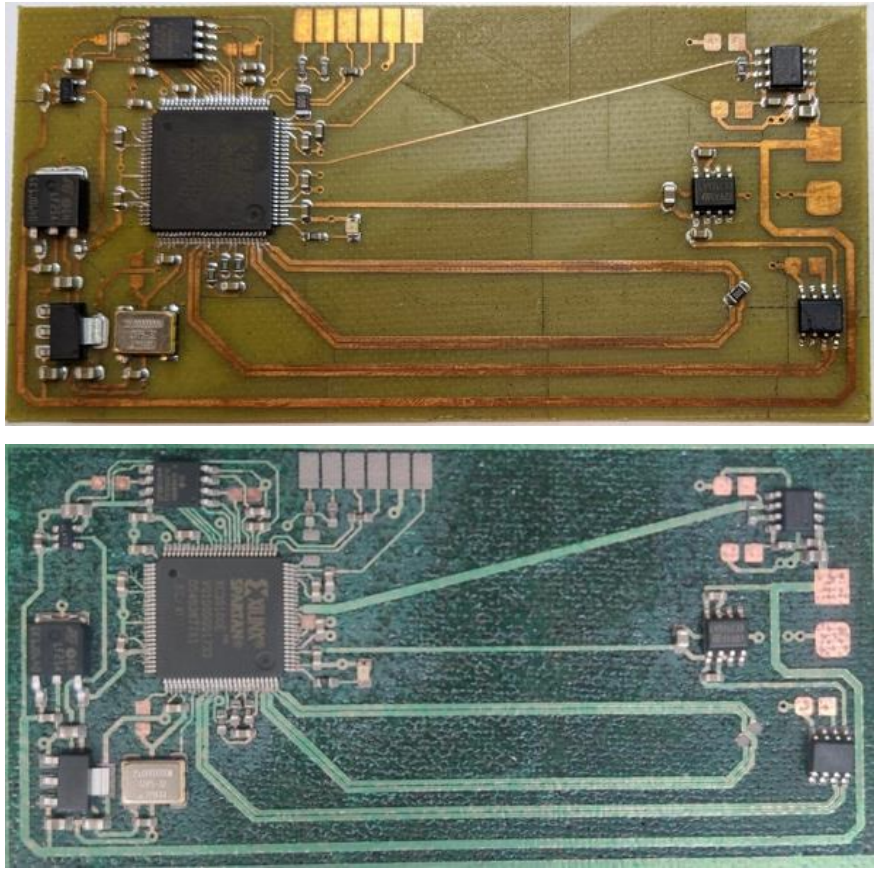
APPLICATION TESTS – FPGA TEST BOARD



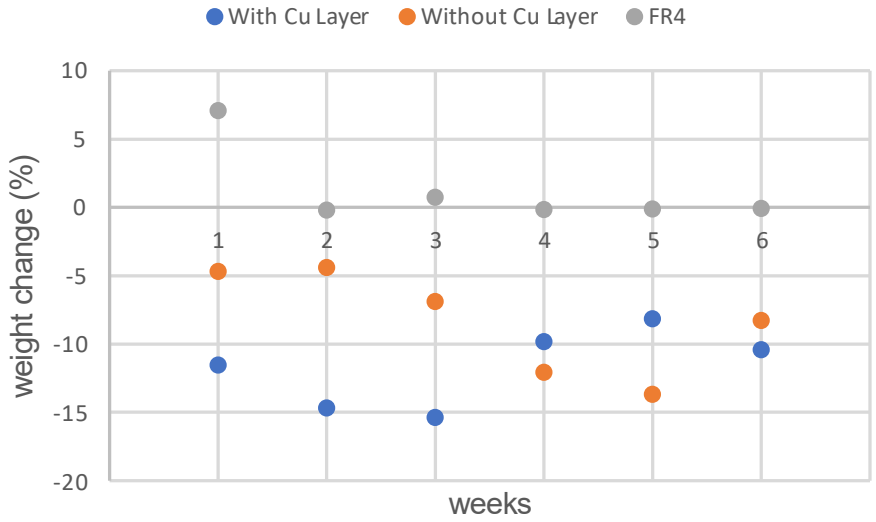
FR4 (top) and PLA/Flax (Bottom) test boards

- Does not match the current norms of the Association Connecting Electronics Industries (IPC).
- In radiofrequency field, it has been shown that this substrate is suitable with good performance for high-frequency applications, like antenna manufacturing.
- A critical point for the future is controlling the substrate biodegradability during its active life.
- A high-speed digital circuit design could be adapted to the new PLA/flax substrate.

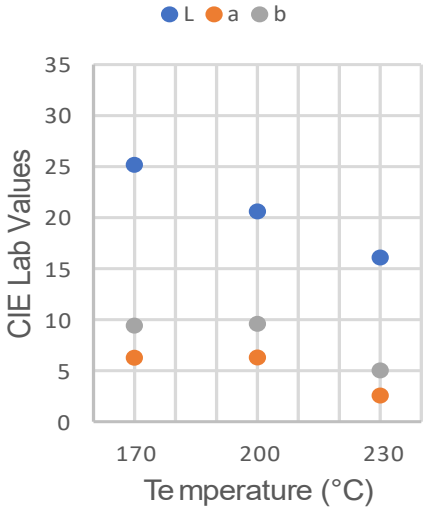
Vincent Grennerat, Pascal Xavier, Pierre-Olivier Jeannin, Nicolas Corrao, Attila Géczy, High-Speed Digital Electronics Board on a Novel Biobased and Biodegradable Substrate, IEEE ISSE 2023 Conference (submitted)

DEGRADATION TESTS

- Short tests for a few weeks run in composting bin.
- After 2-3 weeks, significant changes are reported in weight.
- Susceptibility to harsh environment. No significant decomposition in 6-7 weeks.



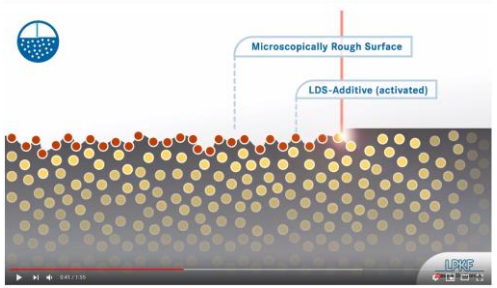
Further tests: decomposition with reflow heating: around 230 °C the substrates lose their flexural character and become brittle and discolored.



Csaba Farkas, Olivér Krammer, András Csiszár, István Hajdu, László Gál and Attila Géczy, Decomposition study of sustainable biodegradable Printed Circuit Boards, IEEE ISSE 2023 (submitted)

FUTURE QUESTIONS?

- Additive technologies?
- LDS? Rapid prototyping, 3D printing?



COMMUNICATION

Sparkfun.com

Great prospects of:
- application in commercial scenarios
- general/focused communication.
- application in education.

TECHNOLOGY

- Ergonomic and mechanic tests on the substrates
- Important questions:

Quality aspects?

Reliability?

- Thermal parameters?
- Thermal conductivity?

- Dielectric, RF parameters?

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CONCLUSIONS:

- Working simple demonstration circuits on **novel PLA-flax PCB** substrate.
- Flame retarded ✓
- Weave reinforced ✓
- Biodegradable substrate ✓
- Subtractive technology ✓
- Applied solder mask ✓
- Low temperature reflow compatible ✓
- Thermal and RF characterization – promising first results. ✓

BENEFITS/DRAWBACKS:

+ promoting sustainability

+ compatible with current manufacturing technologies

+ great market opportunity

+ can be based on EU sources.

- optimization for quality and realiability requires further work.
- Limited applicability. (commercial electronics)

B/D ratio is heavily leaning to benefits.

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