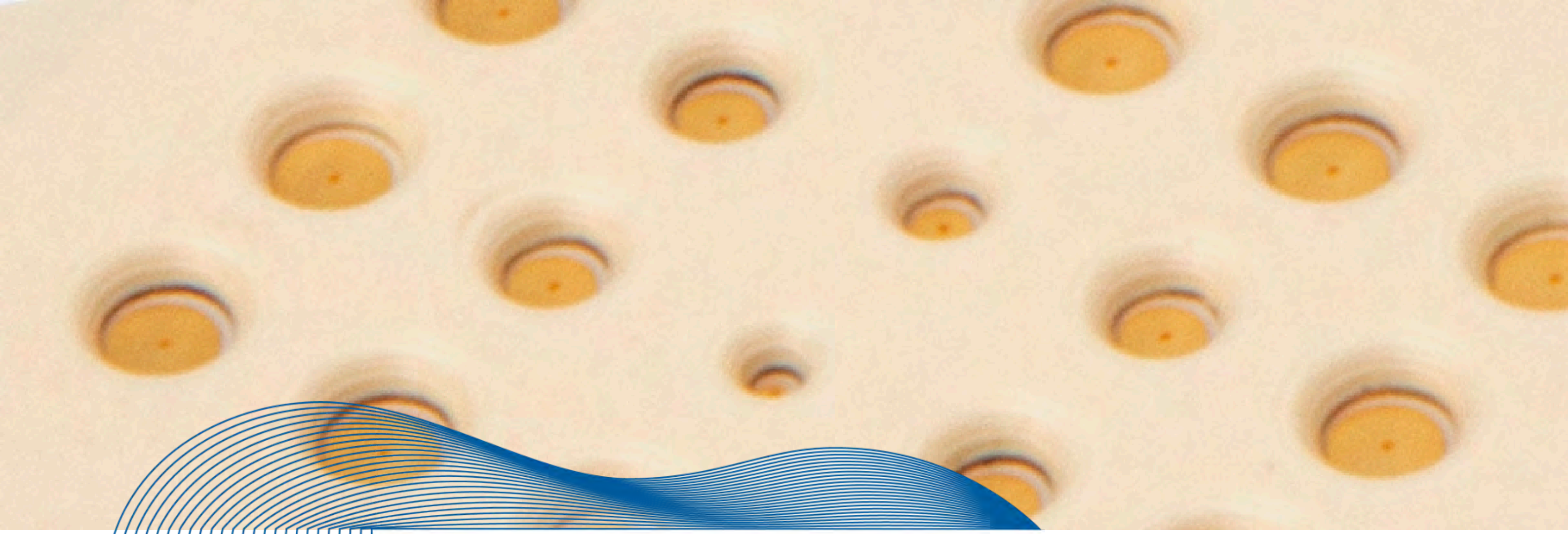

Lab-on-PCB Platform

Cost-Effective Biocompatible Substrate Technology for Lab-on-PCB Applications

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SUMMARY

This study presents a lab-on-PCB platform for in-vitro analysis of biological material, which integrates electronic, electrochemical and optical components with microfluidic structures. The microfluidic components and the housing of the completed device are constructed of injection-molded parts. Electrical functionality is provided by a thin printed circuit board (PCB). The substrate technology is fully biocompatible and can be steam-sterilized if required. An optically transparent substrate material is available to allow the integration of optical techniques. The substrate integrates micro-electronic components and fully encapsulates them against the biological material to be analyzed. The substrate material LCP (Liquid Crystal Polymer), a chemically and biologically stable thermoplastic material, provides superior resistance to moisture and gas permeation to a degree only hitherto seen in glass or ceramic materials, at significantly lower cost. Potential applications of this lab-on-PCB platform technology are point-of-care diagnostics, analysis of organoid tissue and other in-vitro analysis techniques involving electrical and optical measurements.

Liquid Crystal Polymer (LCP) is a high-performance thermoplastic material that can be thermoformed (even as a complex multilayer flex with embedded thin film traces) to any desired shape. Other benefits are its low moisture absorption, gas and water permeability and chemical stability. LCP can be bonded to itself, allowing multilayer constructions with a homogenous structure. LCP can also be used as an encapsulant for micro-electronic components.

Description	Unit	LCP	Polyimide *(transparent)*
Available film thicknesses	µm	25, 50, 100	25, 50
Electrical properties			
Dielectric constant (10 GHz)	-	2.9	3.0
Dissipation factor (10 GHz)	-	0.002	0.008
Surface resistivity	Ω	1.0 E16	3.0 E16
Volume resistivity	Ω cm	1.0 E18	4.5 E17
Dielectric strength	kV/mil	3.5	5
Mechanical properties			
Young's modulus	GPa	2.3	4.7
Tensile strength	MPa	280	190
Thermal properties			
CTE, x-y	ppm/K	18	22
CTE, z	ppm/K	200	120
Solder float temperature	°C	> 288	> 300
Melting temperature / Glass transition	°C	330	343
Other properties			
Moisture absorption *(23°C, 24h)*	%	0.04	0.8
Water vapor transmission rate *(film thickness: 50 µm)*	$g/m^2/d$	<0.01 *(detection limit)*	5
Optical transmittance	ISO 14782	Opaque	86%
Flammability	-	UL 94 VTM-0	UL 94 V0

Table 1. Properties of substrate materials

Polyimide is a thermoset polymer material that provides optical transmittance together with good tolerance of high temperatures and excellent flexural endurance.

Device Construction Principle

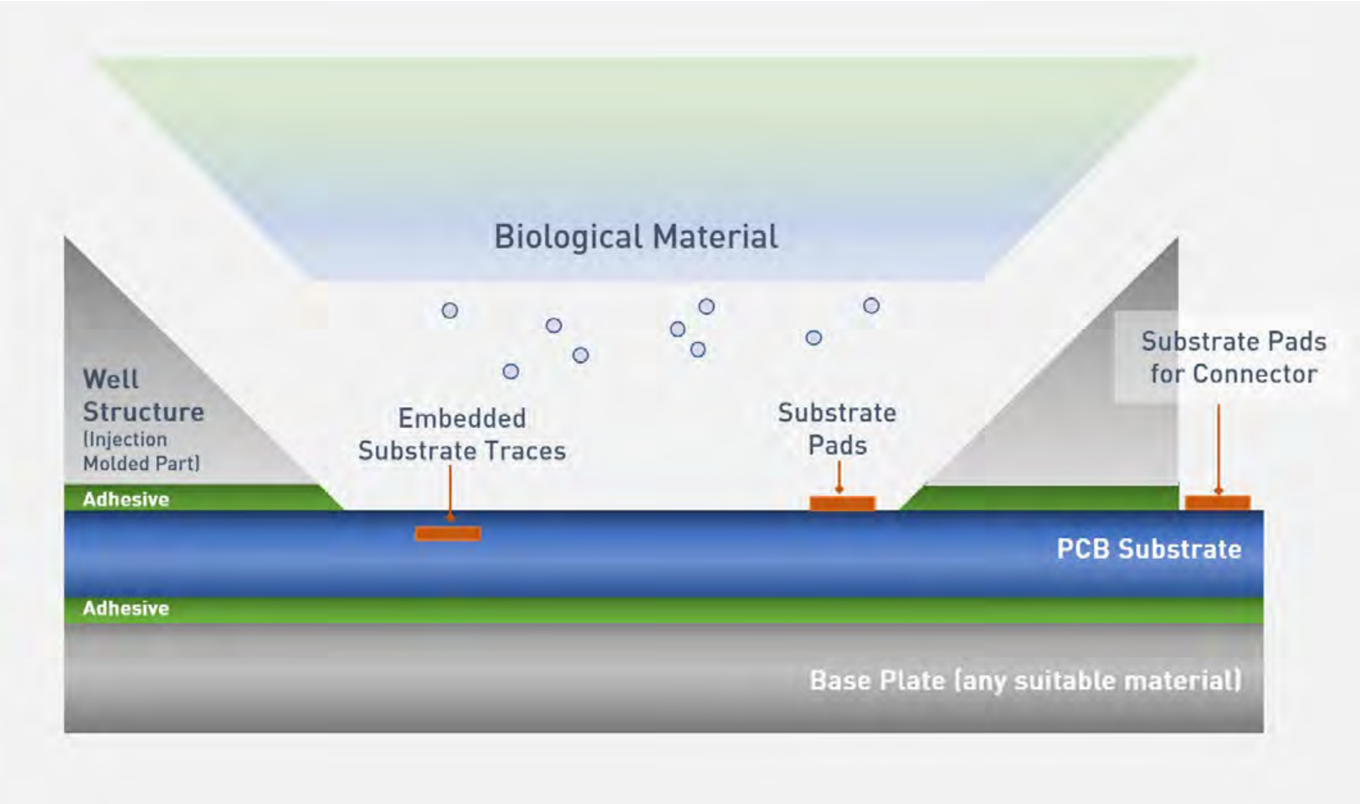
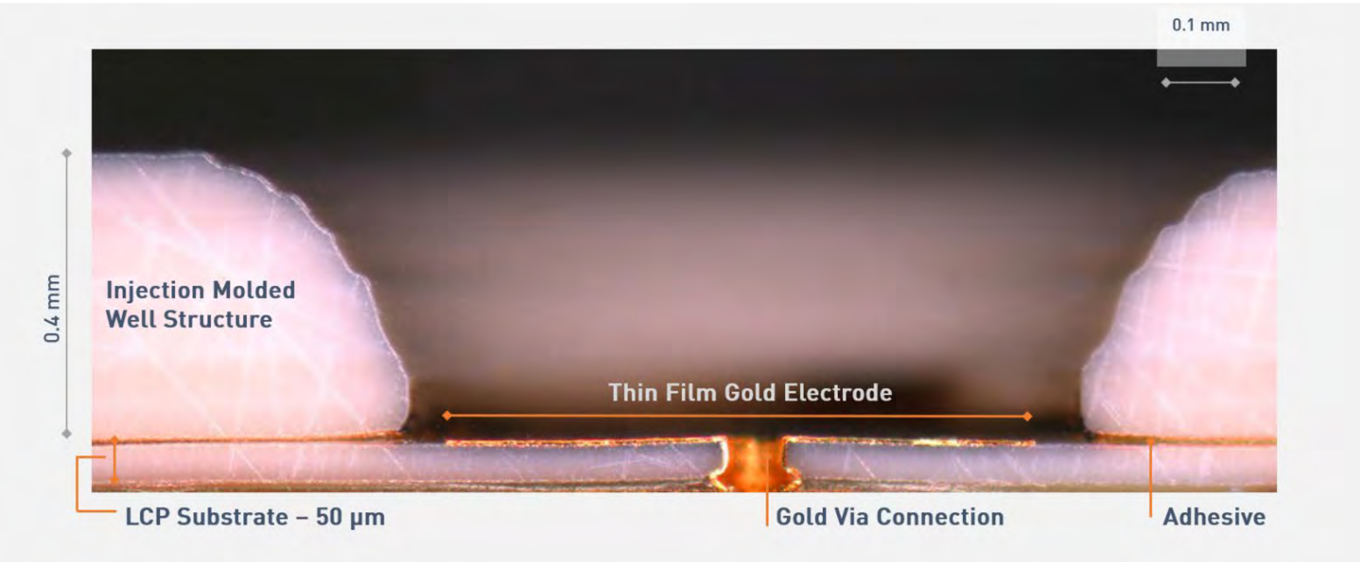


Figure 1. Lab-on-PCB construction principle. A well structure containing the biological material to be analyzed is attached with an adhesive to a PCB substrate. The PCB carries all electrical functionality required for a Lab-on-Chip application.

The construction principle is depicted in Fig. 1. A well structure made by injection molding from a suitable thermoplastic material (e.g. PC, LCP, PEEK, etc.) is attached with a sheet adhesive to a PCB substrate. The PCB carries all electrical functionality required for the Lab-on-Chip and can be either electrically contacted with standard connectors or inserted into an analytical instrument performing the necessary analysis of the electrical signals provided through the PCB. The substrate can be either attached to a base plate or inserted into a standard cartridge typically used for testing of biological material.

Fig. 2 shows a cross section through a product with a well structure made of LCP attached to an LCP substrate with a pure gold electrode. The adhesive used is a pressure-sensitive adhesive that shows some limited squeeze-out under the edge of the well structure.



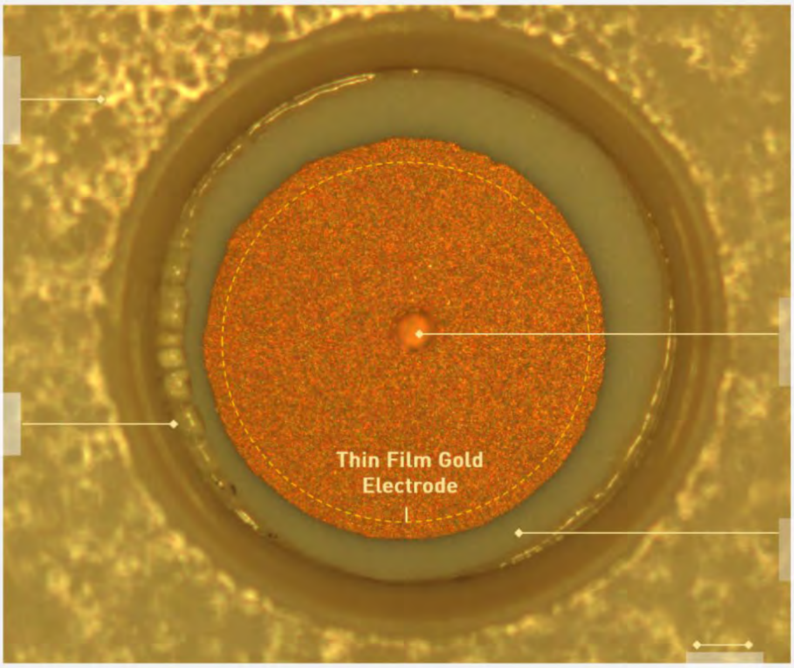


Figure 2. Cross section and top view on a well structure attached to an LCP substrate with a thin-film pure gold electrode.

Dielectric Sensors

Dielectric or capacitance sensors use the change of the capacitance on a fixed capacitance by an adsorbed liquid. The capacitor is formed by interdigitated electrodes covered by either a thin covering layer or the top layer of the substrate. The top layer of the substrate can be thinned down locally by laser ablation to form small trenches to guide and position the liquid exactly over the capacitor. Fig. 3 shows the principle of this sensor. The electric field of the capacitor protrudes into the space above the substrate where the liquid is adsorbed. The dielectric behavior (polarization and attenuation) of the liquid can be analyzed with impedance spectroscopy.

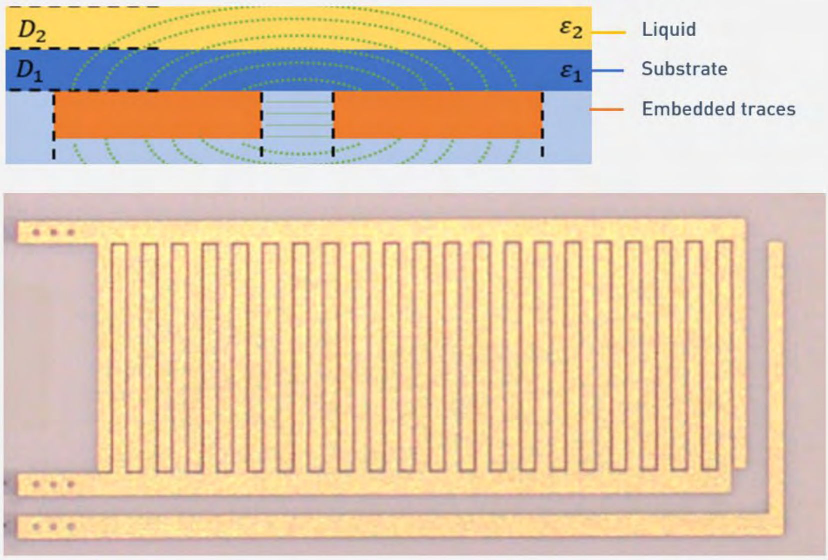


Figure 3. A view of interdigitated electrodes (below) and a schematic cross section of two neighboring traces underneath the substrate surface (above). The interdigitated electrodes define a capacitor whose dielectric properties are changed by an adsorbed liquid on top.

The substrate material LCP is specifically useful for such dielectric sensors, as there is very little water absorption into this material. Fig. 4 shows the impedance spectra of the structure shown in Fig. 3 when immersed in phosphate-buffered saline solution (PBS) over a time range of 6 months continued soaking. There is no change in the impedance measurable over this time range, demonstrating that there is no ingress of water into the structure.

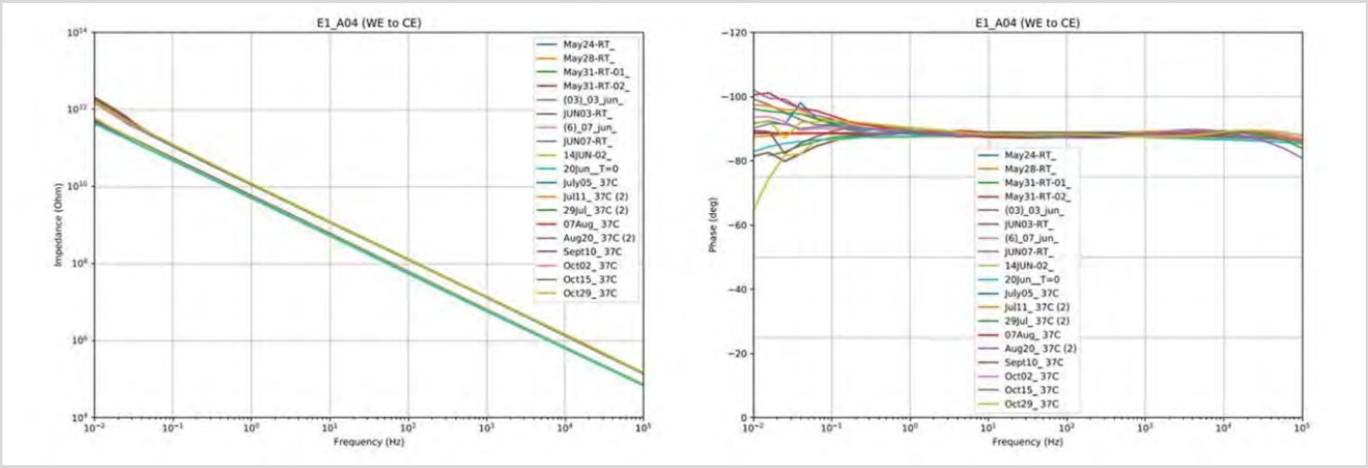


Figure 4. Impedance spectrum of the interdigitated electrodes immersed in saline solution. The graph on the left shows the impedance, and the graph on the right illustrates the phase where the frequency ranged from 0.01 Hz to 10 kHz. Multiple curves from measurements over a period of 6 months are shown.

When material is adsorbed on top of the interdigitated capacitor, the impedance spectra will change due to the specific polarization and absorption of the adsorbed material. This can be used to analyze the material, e.g., for water content or even more sophisticated investigations.

Electrochemical Sensors

Electrochemical sensors can be formed by depositing different metals on top of the conductors. Platinum coatings are often used to form reference electrodes. Platinum is electroplated in a thin layer on top of a pure gold electrode. Fig. 5 shows a FIB (focused ion beam) cross section through a gold electrode with a platinum layer deposited on top of the gold. The platinum layer is about 165 nm thick.

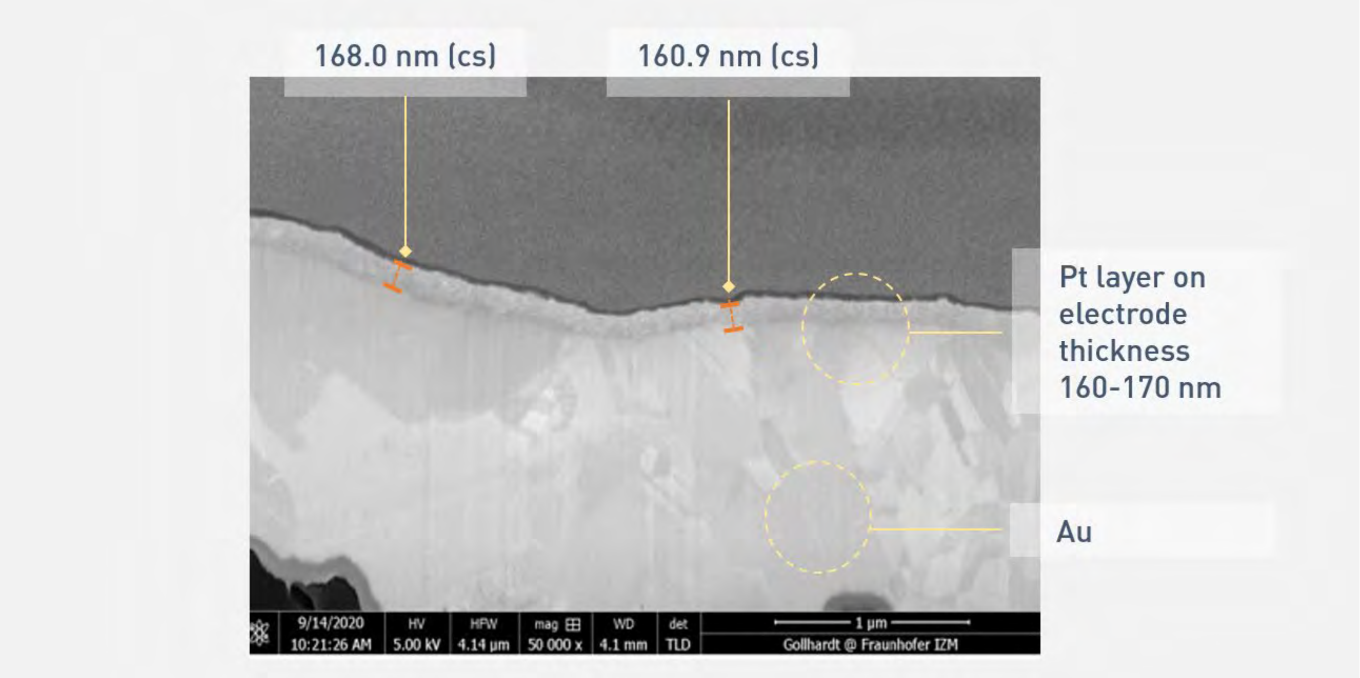


Figure 5. Thin platinum surface coating on a pure gold electrode.

If even lower electrochemical impedance at low frequencies are required, a platinum-iridium layer can be deposited on top of the gold electrode rather than platinum alone. Fig. 6 shows typical Bode plots (impedance over frequency) for different electrode metals that can be used on PCB substrates.

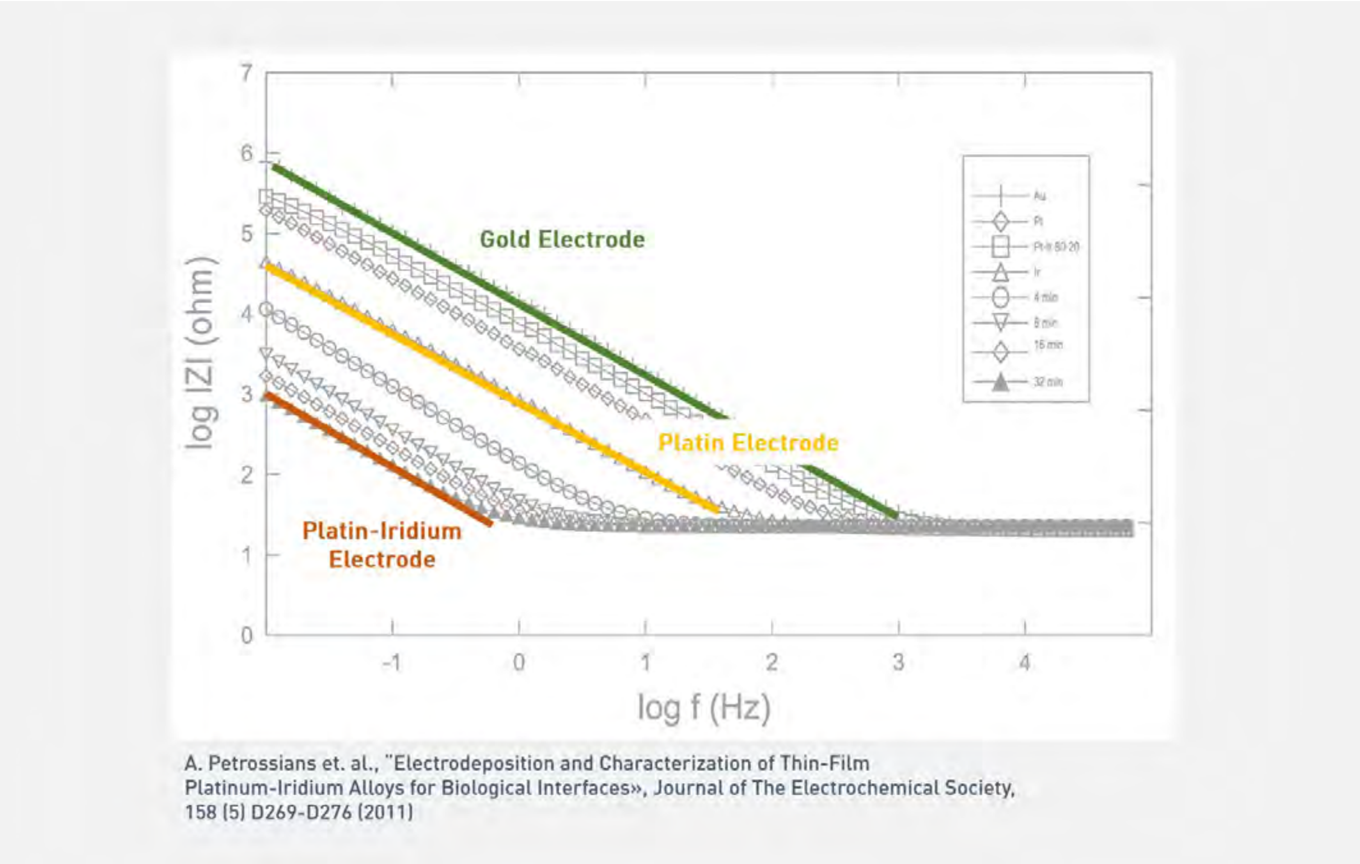


Figure 6. Bode plots of gold, platinum and platinum-iridium electrodes.

It is also possible to deposit screen printable metal pastes on top of gold or platinum electrodes. Fig. 7 shows a screen printed and cured AgCl paste deposited on a small electrode pad measuring 0.3 x 0.6 mm. In this case it is beneficial if a covering layer or a solder mask defines the pad and forms a cavity in which the metal paste is deposited.

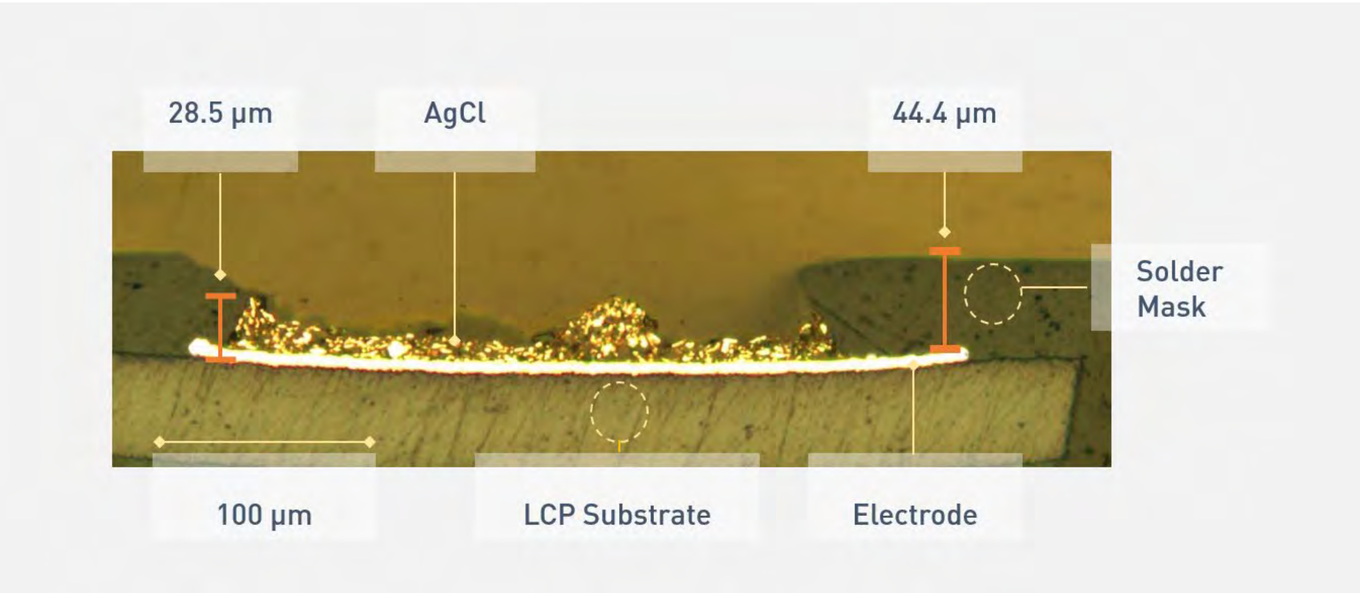


Figure 7. AgCl deposited on solder mask-defined electrode with a width of 300 µm (opening).

Conclusion

By using inexpensive substrate materials such as LCP and polyimide together with PCB manufacturing processes such as the electroplating of metals, it is possible to provide a cost-effective platform for Lab-on-PCB applications.

About DYCONEX

DYCONEX, a company of the Micro Systems Technologies (MST) group, has more than 50 years of experience in manufacturing highly complex flexible, rigid-flex, and rigid high-density interconnect/ microvia printed circuit boards for applications where miniaturization, increased functionality, quality, and reliability are critical. DYCONEX supplies complex circuit boards, LCP and chip substrate solutions to leading manufacturers around the world in the areas of medical technology, space and aviation, industrial electronics, telecommunications, and semiconductor technology. During the design phase, DYCONEX offers a variety of services to help clients develop the optimal solution for their application with an eye toward the best manufacturing processes.

About the Author

Dr. Eckardt Bihler graduated with a PhD in solid state physics from the University of Stuttgart. In his more than 30-year career in the microelectronics industry he has gained considerable experience in ceramic and organic packaging, semiconductor design, photovoltaics and printed circuit board processing technologies. He holds more than 15 patents and patent applications. He works for DYCONEX as a business development and program manager.

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