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The Use of ALD Layers for Hermetic Encapsulation in the Development of a Flexible Implantable Micro Electrode for Neural Recording and Stimulation

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INTRODUCTION

The use of electronic microsystems as medical implants gains interests due to the combination of superior device functionality with extreme miniaturization. One of the main challenges is the hermetic encapsulation of small implantable devices which contain electrodes for recording and stimulation. In this work, the goal is to encapsulate a thinned CMOS chip (35 µm) with neural electrodes. Following requirements for the encapsulation material stack must be taken into account:

- Flexibility and good mechanical properties and stability.
- Corrosion protection of the encapsulated electronic devices materials which are not biocompatible.
- Extremely good bi-directional barrier properties against diffusion of water, ions and gases.
- Very long (up to 20 years) biostability against body fluids and biomolecules.

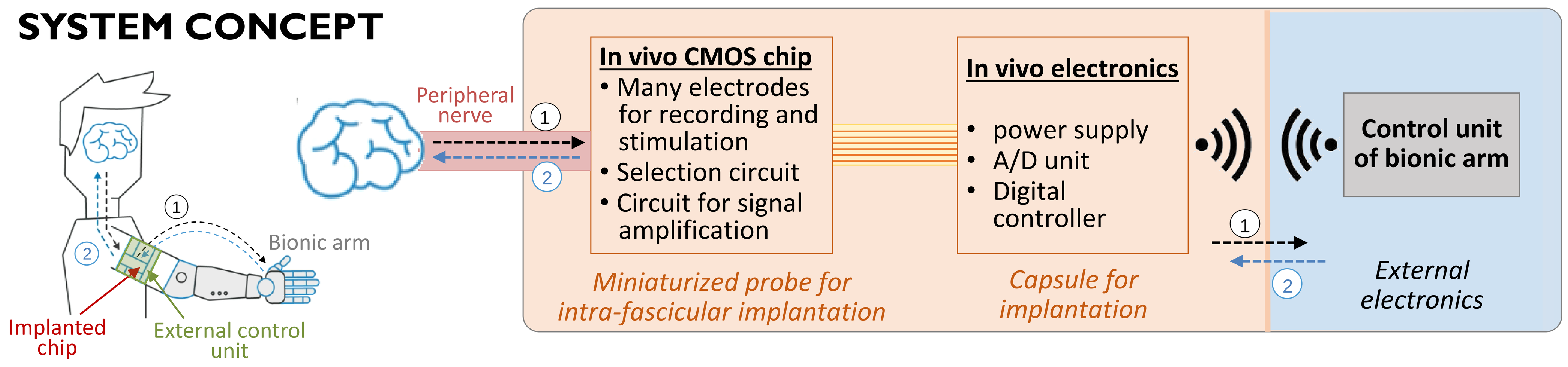
EXPERIMENTAL

Water vapor transmission rate (WVTR) is determined with a HighBarSens instrument from SEMPA SYSTEMS GmbH

Corrosion inspection and EIS (Electrochemical impedance spectroscopy) are performed on patterned Cu samples with barrier layers on top in PBS at 60°C.

ALD depositions are performed on a Ultratech Savannah instrument at 250°C.

SYSTEM CONCEPT



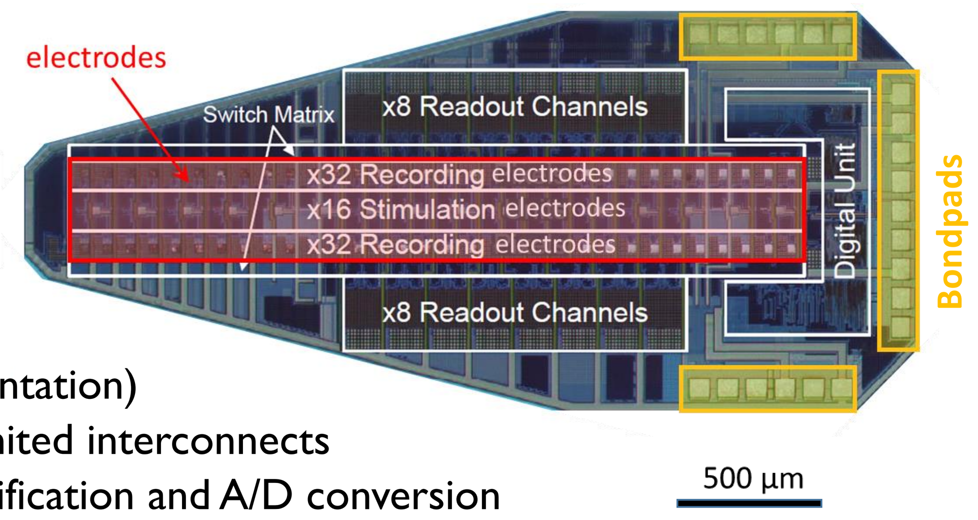
Implanted electronic system for thought-driven control of bionic arm

→ CMOS-based high-density transverse intra-fascicular multichannel electrode (hd-TIME) probe.

- optimized implantation procedure for limited tissue damage
- dedicated chip package based on the FITEP (Flexible Implantable Thin Electronic Package) technology platform

CMOS CHIP

- 64 recording & 16 stimulation electrodes
- Switch matrix for selection of 16 optimum located electrodes (after implantation)
- Multiplexing unit → limited interconnects
- Recorded signals: amplification and A/D conversion
- Stimulation signals composed in digital unit
- Ultra-low power consumption: 1.12mW (measured in recording mode)
- 0.13um CMOS process



MATERIAL SELECTION for chip encapsulation with long term hermeticity

ALD stack [HfOx(8 nm)-AlOx(20 nm)-HfOx(8 nm)]

- Biocompatible and biostable
- Almost pin hole free
- Ultra high barrier properties
- Flexible when sandwiched between 2 PI layers

ALD AlOx alone is widely used for OLED encapsulation due to its excellent barrier properties against water vapor, gases and ions. However, in direct contact with water, the AlOx is prone to hydrolysis. Therefore, the AlOx is capped on both sides with HfOx which possesses a much better chemical stability in aqueous environment.

Polyimide (PI2611)

- Biocompatible
- Applied via spin-coating
- Excellent flexibility, mechanical properties
- Very good chemical and thermal stability

PI (5.5 µm)
ALD stack
PI (5.5 µm)

ADHESION between Polyimide and ALD layers

Good adhesion between PI and ALD stack is very important. Poor adhesion can lead to local delamination and blister formation where water can be accumulated. This creates leakage pads and results in increased WVTR values.

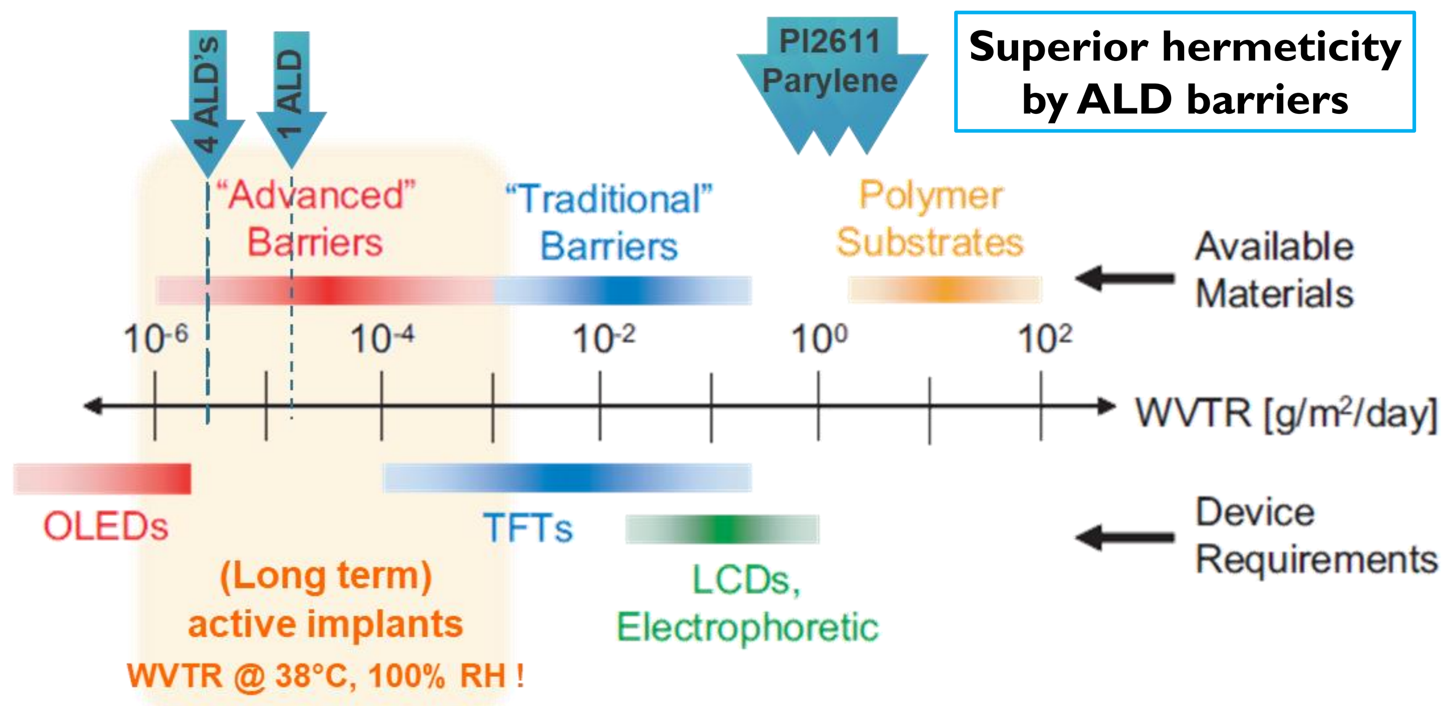
- The adhesion of PI on the ALD stack is largely improved by modifying the ALD surface with APTES (3-aminopropyl-triethoxysilane).
- Good adhesion of the ALD stack on PI is obtained by roughening the PI surface through dry etching.

WVTR Results

The WVTR is determined on a PI/HfOx-AlOx-HfOx/PI film with adapted setup to achieve a RH of 100%.

- WVTR = 2.5 10^{-5} g/m²day (38°C and 100% RH) in the steady-state regime.
- 3 or 4 dyads of these stack lead to values in the order of 10^{-6} g/m²day.

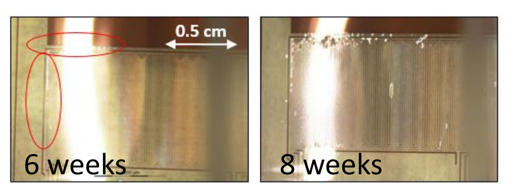
Center Figure:
Water Vapor Transmission Rates (WVTR) requirements for specific applications, and WVTR ranges of various barrier materials. Optimized at imec/CMST: stacks of ceramic ALD barriers with very low WVTR. By combining polymers with an optimized ALD barrier, WVTR improves with 4 orders of magnitude. Using more or thicker ALD layers improves the diffusion barrier properties even more.



Protection of Cu patterns by ALD barrier

Cu patterns with protective barrier are immersed in PBS @60°C, inspection by Cu resistivity and EIS check

- **Barrier: 11um polyimide PI2611**



After 6 weeks in PBS:
→ blisters occur
After several months:
→ Cu is corroded

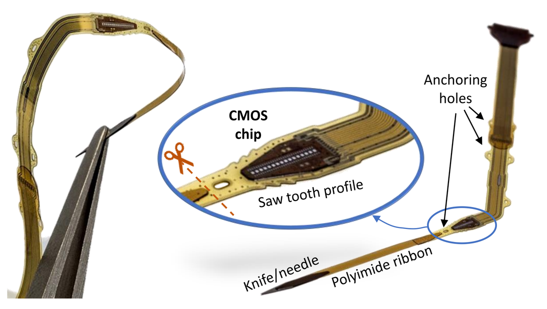
- **Barrier: 5.5um PI2611 / ALD stack / 5.5um PI2611**

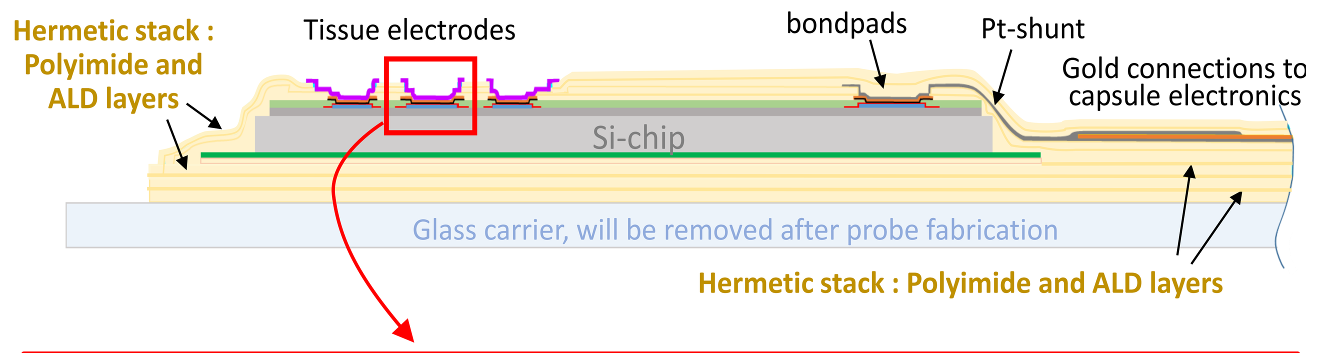
After 142 weeks in PBS @60°C (equiv. to > 13years at 37°C): samples still perfect!
- no blisters, no corrosion
- Cu meanders in perfect condition
- EIS shows barrier is perfectly stable

HERMETIC BIOCOMPATIBLE CHIP PACKAGING

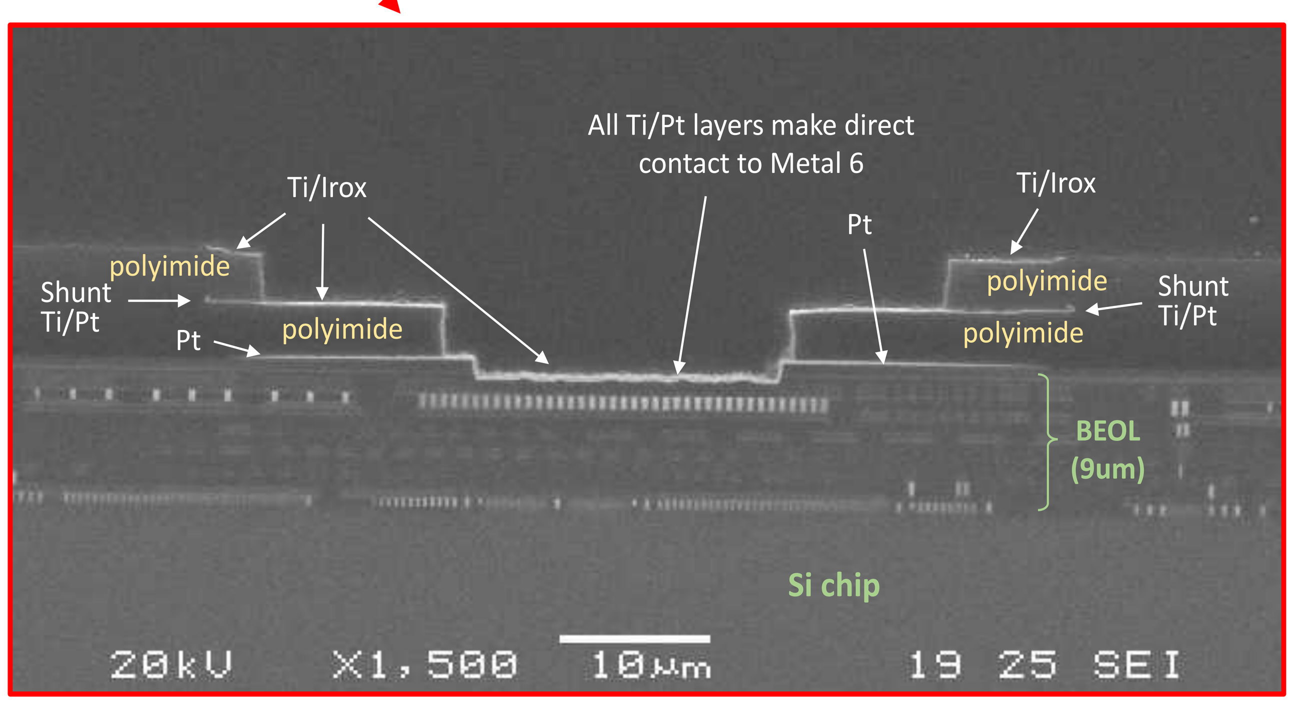
Chip encapsulation process

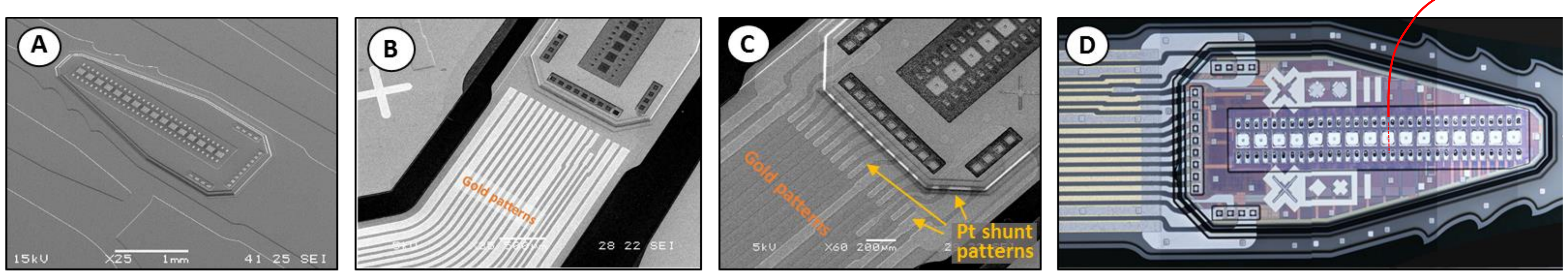
- Wafer level post-processing (extra passivation and CMP , TiN patch on bondpads & electrodes)
- Wafer dicing and thinning down to 35um → rectangular thin chips
- Thin chip placement on glass carrier with polyimide/ALD barrier multi-layers
- Chip singulation (triangular-like CMOS probes for smooth surgical insertion)
- Processing of top barrier multi-layers combined with Pt-patch as diffusion barrier and Au-Pt metallization for fanout of CMOS chip (SEM picture a, b, c)
- Irox electrode fabrication (picture d)
- Probe assembly: coupling of packaged CMOS probe with polyimide/gold extension cable and with SST insertion knife/needle





Cross-section





A: After chip placement + deposition + patterning of first PI top layer
B: After polyimide/ALD top layer deposition and gold metallization
C: After gold and platinum metallization
D: After IrOx electrode fabrication and full probe laser cutting

CONCLUSIONS

- **The biocompatible PI/HfOx-AlOx-HfOx/PI stack shows excellent barrier properties.**
- **Acceleration tests reveal stability up to 13 years at 38°C**
- **The stack is applied and integrated as hermetic encapsulation of a flexible implant containing a multi-electrode CMOS chip for neural stimulation and recording.**

References

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