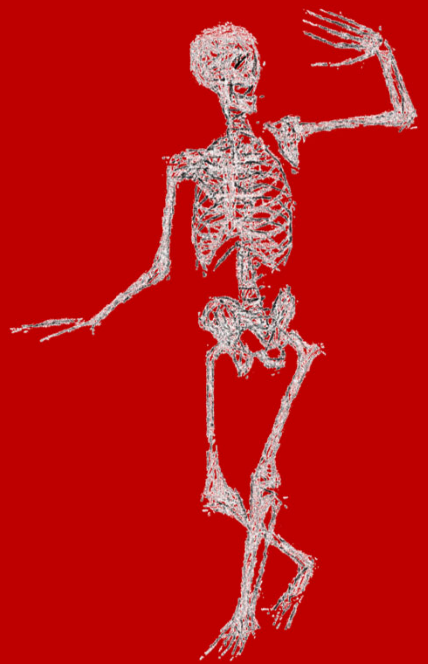
Empa
Materials Science and Technology

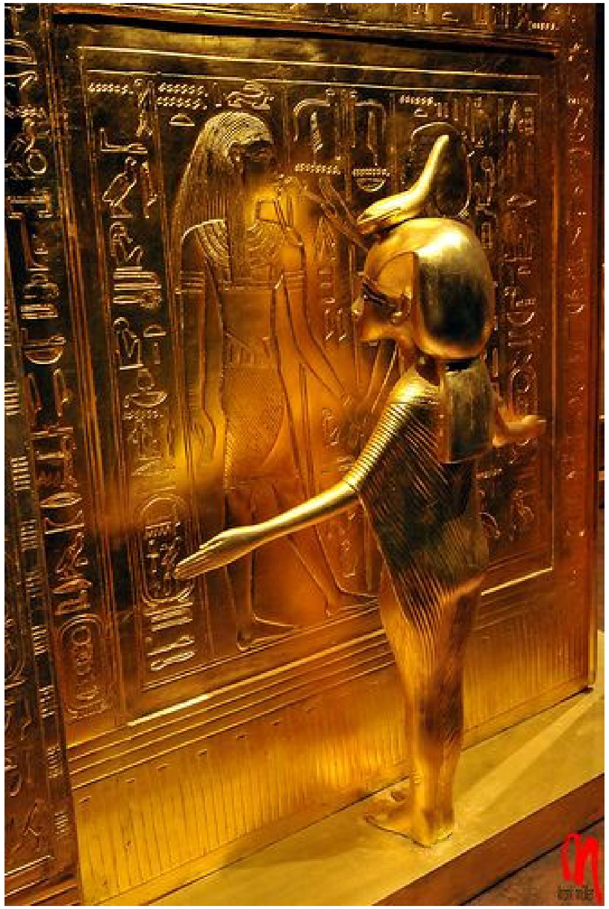


Dünne Schichten in der Medizintechnik: Innovation für Implantate, Diagnostik und chirurgische Präzision

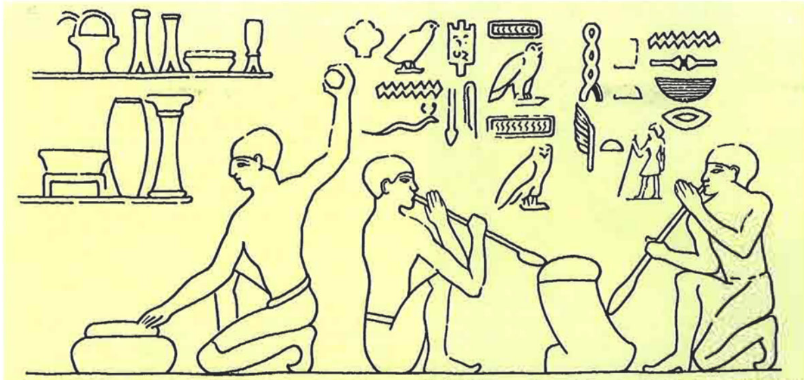
27.05.2025

Kerstin Thorwarth

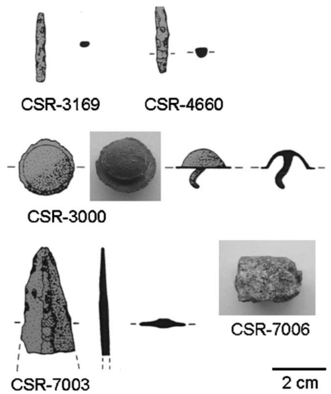
First known attempts of coatings



found in the tomb of Pharaoh Tutankhamun
(“King Tut,” 18th Dynasty, rule 1332–1323 BC).

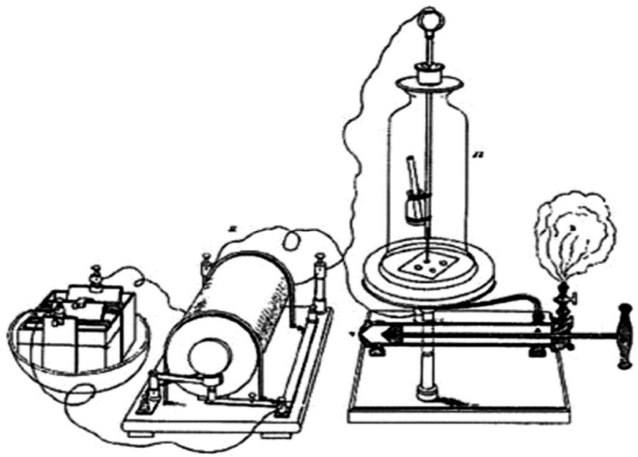


This illustration from an ancient Egyptian tomb at Saqqara (2500 B.C.) shows the melting of gold with the assistance of blowpipes and the beating of gold with a rounded stone held in the hand



...up to today

Physical Vapour Deposition (PVD) in the middle 19th century, first publication on sputtering in 1852



PVD setup 1852 by William Grove

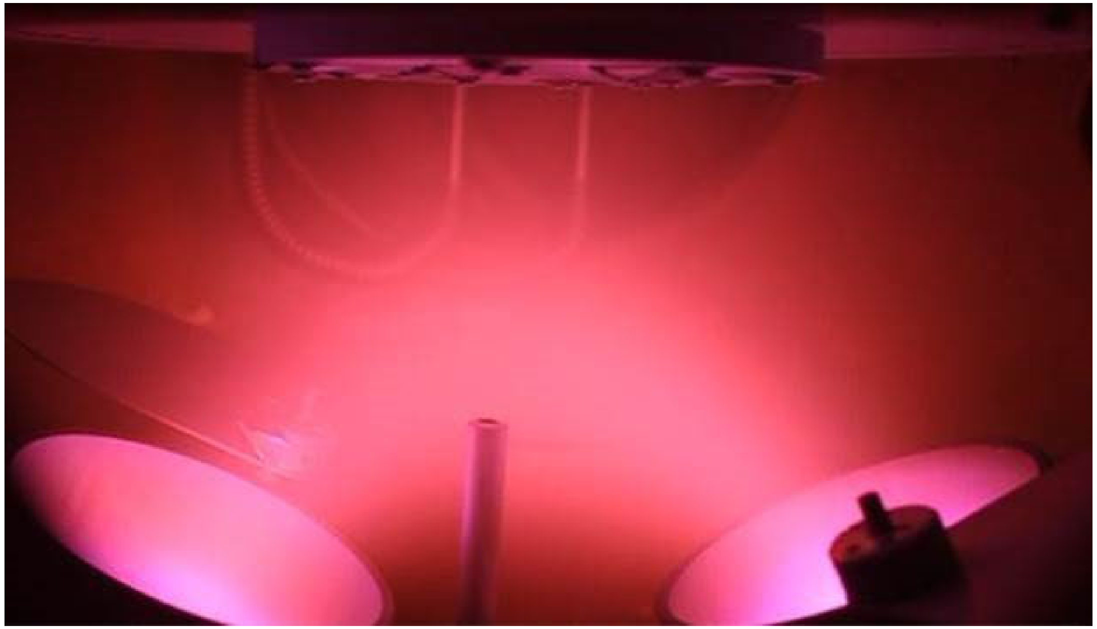
PVD setup 2024 by Oerlikon Balzers

PVD market 2023: $27.1 billion; compound annual growth rate of 8.6%

https://globenewswire.com

Joe Greene:
Tracing the recorded history of thin-film sputter deposition: From the 1800s to 2017
Journal of Vacuum Science & Technology A **35**, 05C204 (2017)

Plasma



Usage of Coatings for Medical Applications:

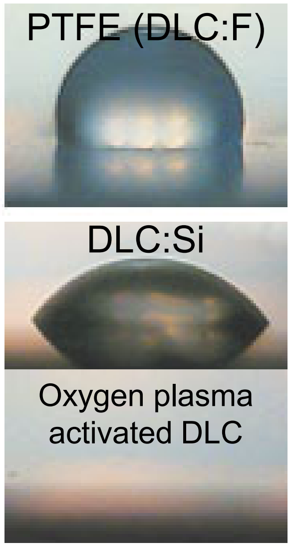
Implants
Tools
Diagnostic

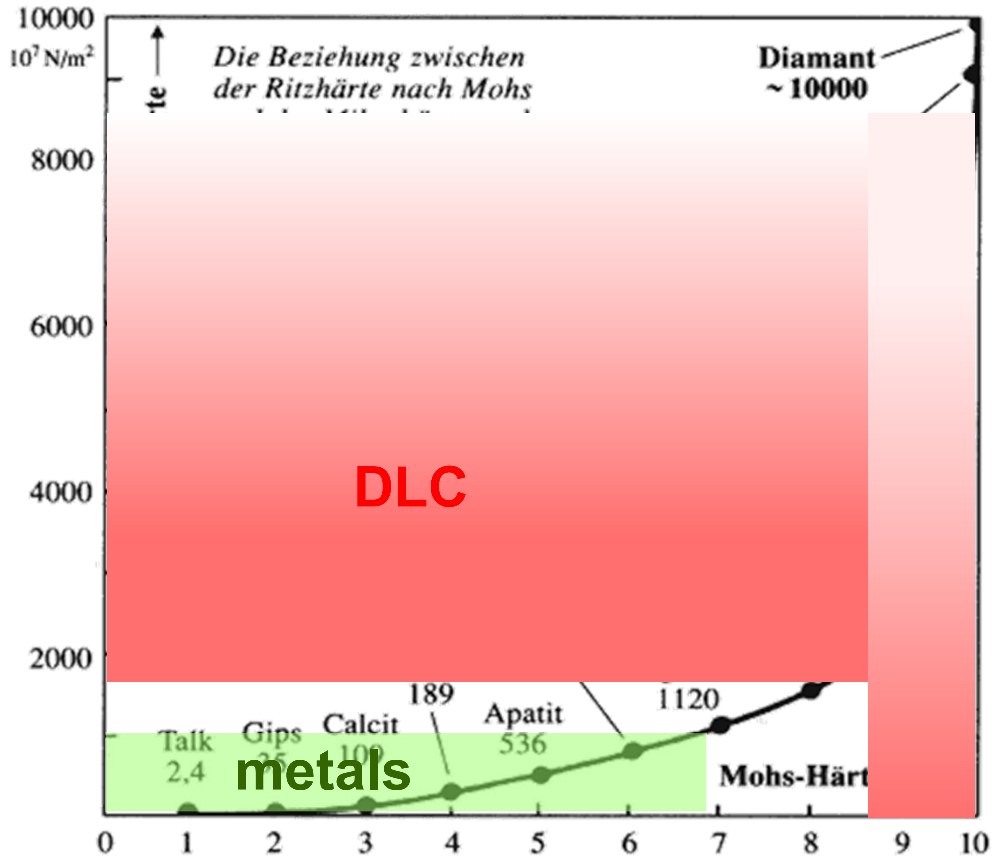
Diamond-like Carbon (DLC): Medical Applications

Diamond Like Carbon (DLC): Advantages

DLC is a class of condensed C-H materials and exists only as a thin film (vacuum plasma deposition)
Due to its high internal stress it has a tendency to delaminate

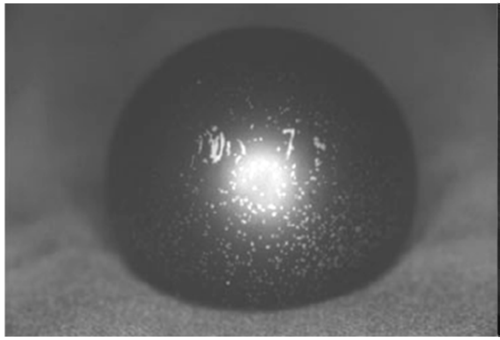
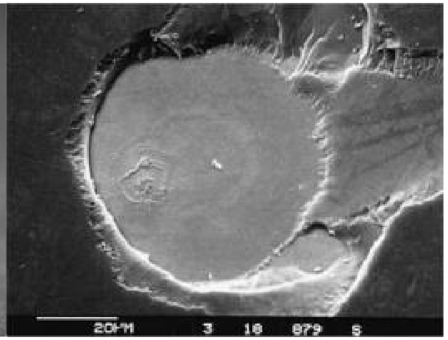
- High hardness (20…70 GPa)
- Conforms to substrate
- Ultra-low friction coefficient against many materials
- Very low wear
- Chemically inert; insulating; biocompatible as Titanium
- Diffusion barrier
- Dopability, e.g.:
  - F $\Rightarrow$ hydrophobic
  - Ag $\Rightarrow$ antibacterial
  - N $\Rightarrow$ conductive

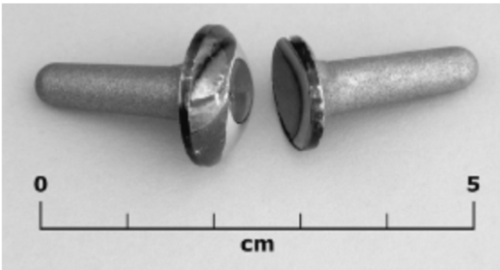


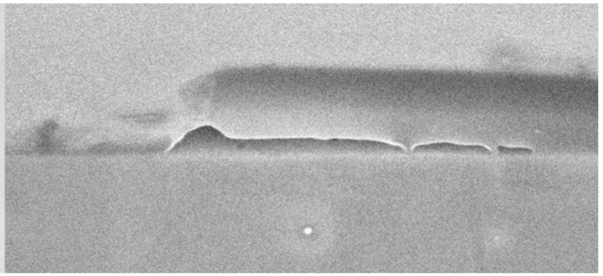


Why are DLC coatings not common on implants?

Short answer: Interface problem!

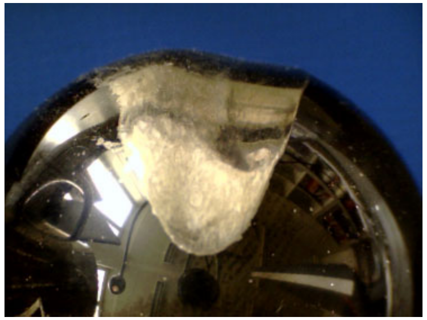





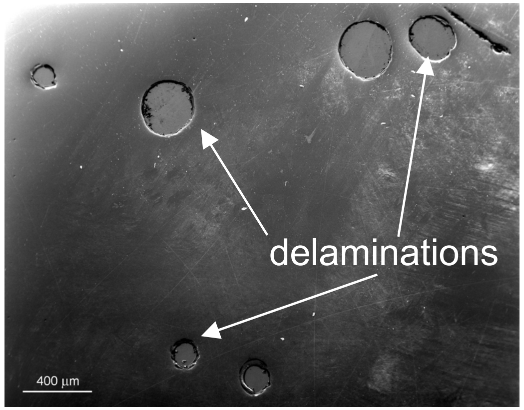
DLC/TiAlV hip joint

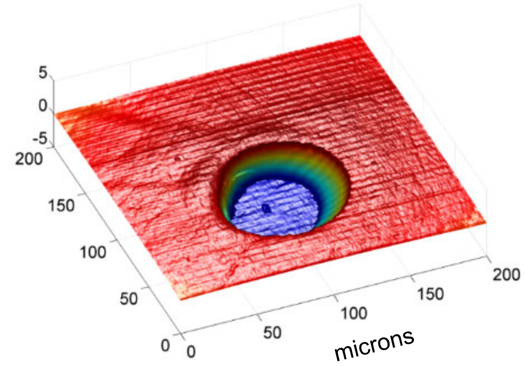
(50% out of 101 implants failed due to aseptic loosening after 8.5 years)

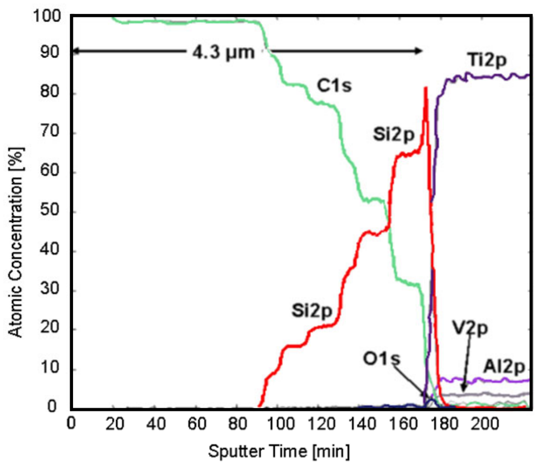
Hauert, Thorwarth et al., Acta Biomater. 8 (2012) 3170-3176

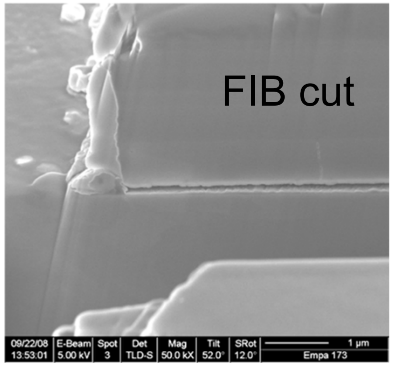


Failed explant









Adhesion in corrosive medium

Delamintion processes

delamination speed

lifetime requirement

$$v=\sum_i f_i(G) \overset{!}{<} v_c$$

interface energy

$$G = G_{intrinsic} + G_{mech}(t)$$

$$f(G) = A$$

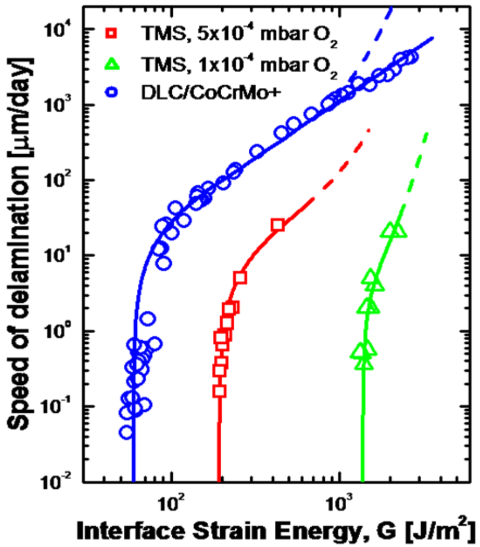
crevice corrosion

$$f(G) = B \cdot (G - G_{th})^C$$

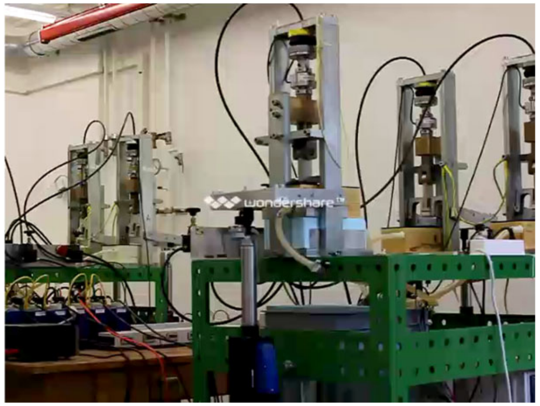
stress-corrosion cracking

$$f(G) = \begin{Bmatrix} 0, G < G_c \\ \infty, G > G_c \end{Bmatrix}$$

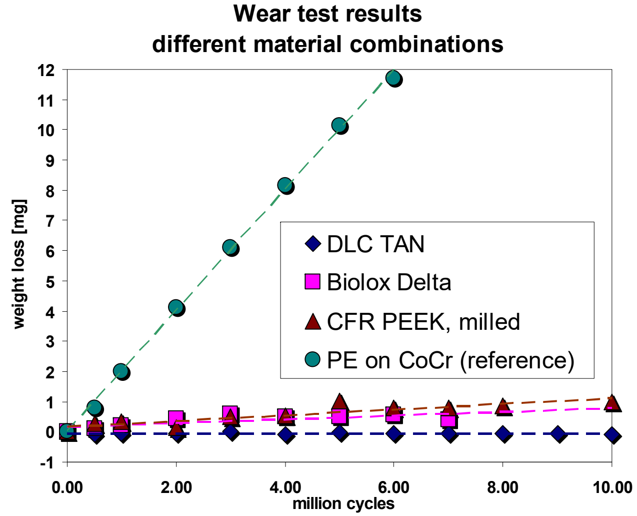
mechanical failure



Achievements



- High stability
  up to 100 Mio cycles
  (100 years of articulation in vivo)



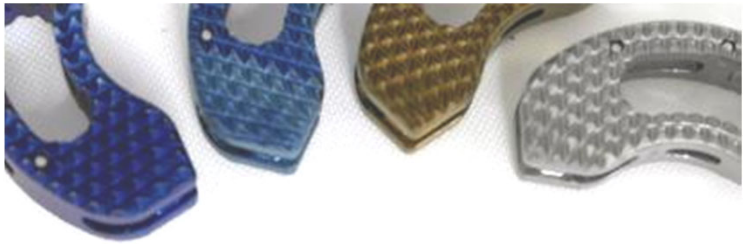
ASTM Simulator (DePuy, Westchester USA)

- „substrate independent“ DLC
  layer system against eggshell
  effect (patent secured)

Coatings on Polymers (e.g. PEEK)

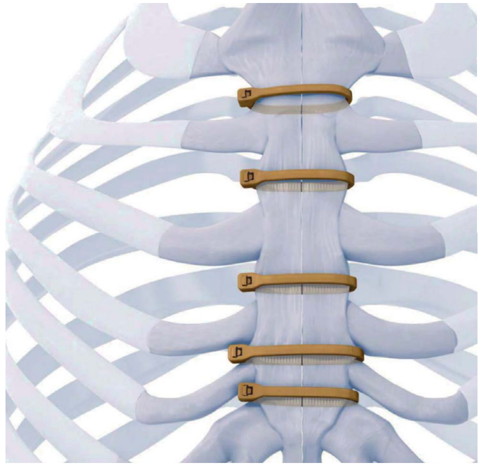
T-PAL PEEK spinal spacer
(Ti, HiPIMS coated at Empa)

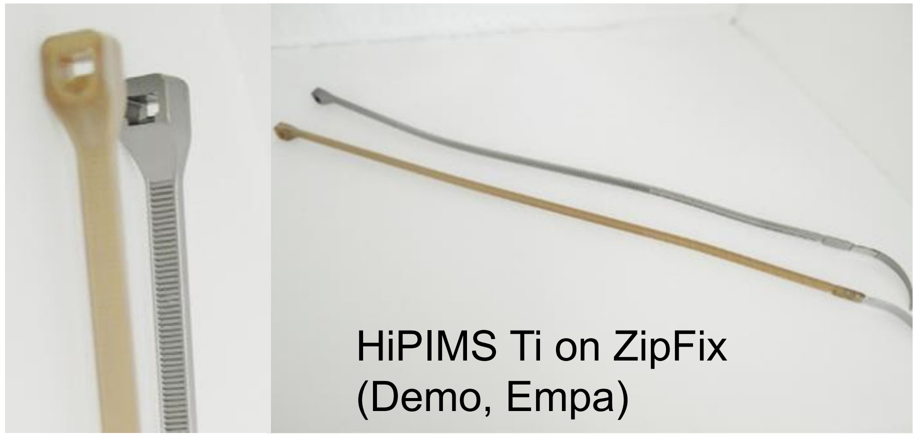
applicable to most PEEK based implants



platform for futher processing

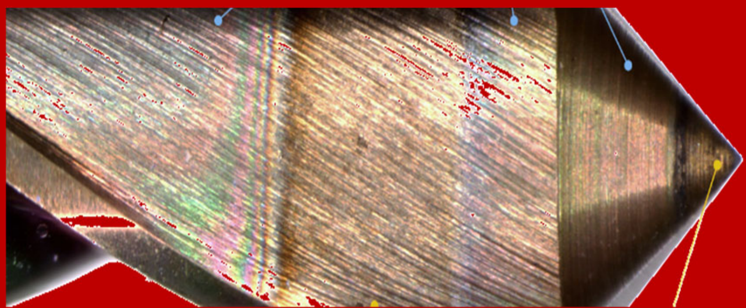
flexible, highly adherent
Ti coating on PEEK





HiPIMS Ti on ZipFix
(Demo, Empa)

Smart Drills for Neuromonitoring



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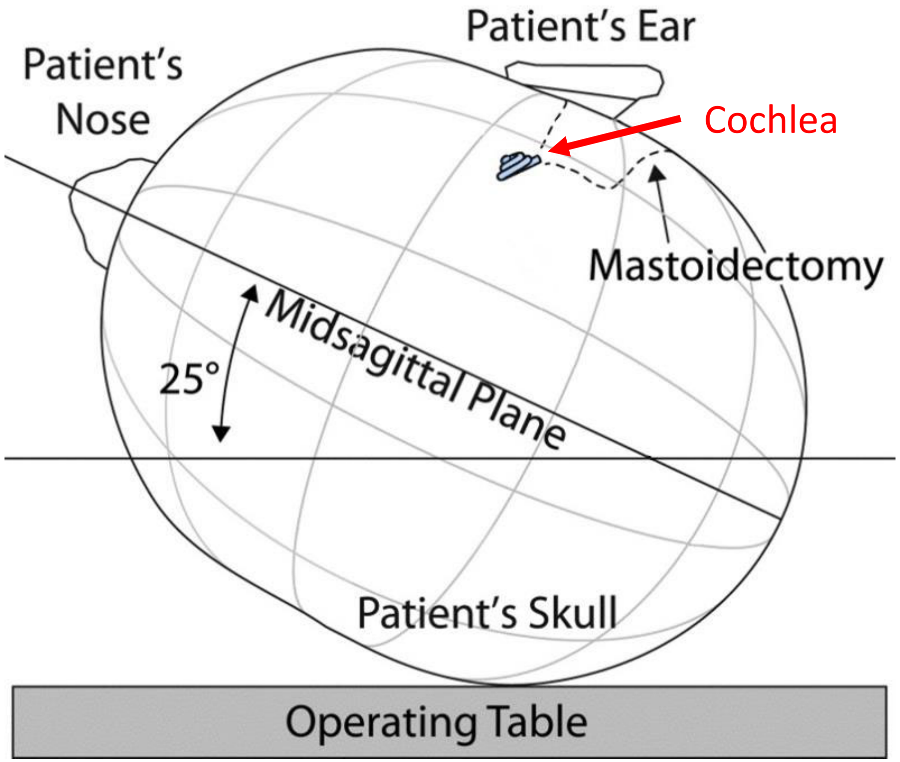
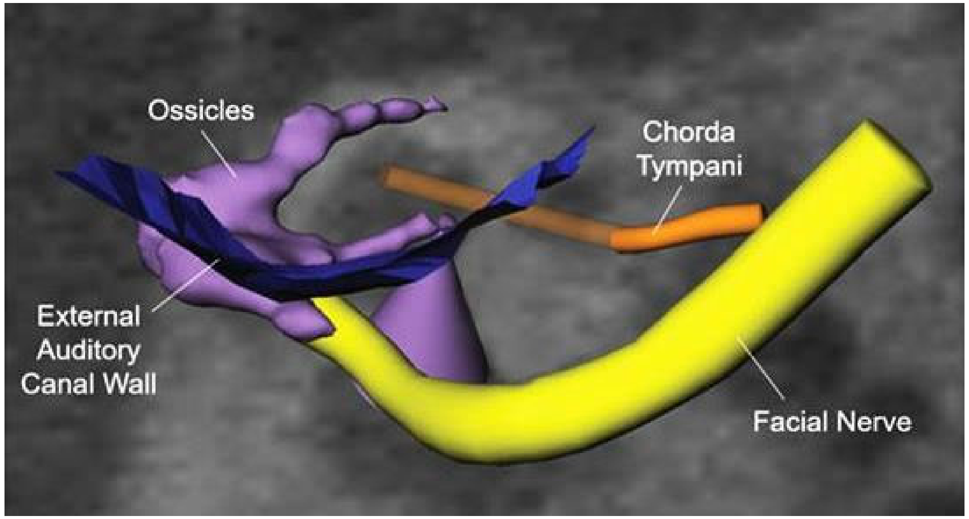
BIOMEDICAL ENGINEERING RESEARCH

Cochlear Implantation Surgery

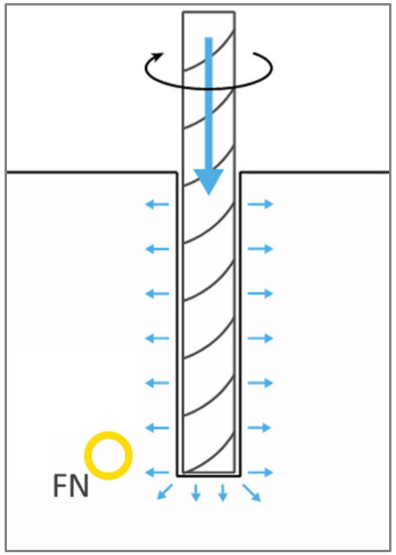
- Severe to profound sensorineural hearing loss

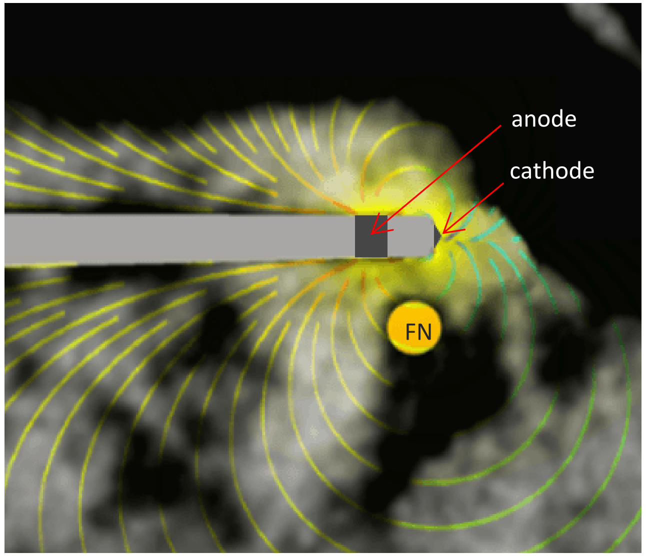


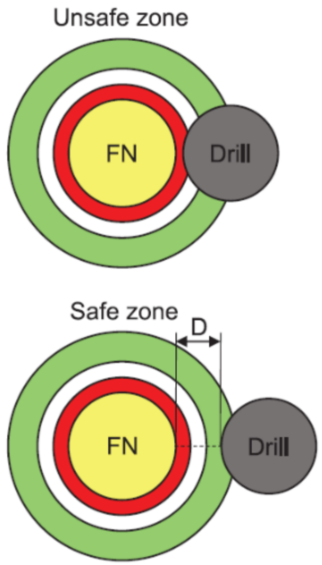


- Important anatomical structures must be avoided and preserved
- Facial nerve and chorda tympani particularly at risk during CI

- Stimulation along bare drill bit:
  → *ineffective due to current distribution along entire tunnel length*
- Stimulation using an insulated probe with ring & cone electrodes:
  → *sensitive and specific detection of facial nerve*





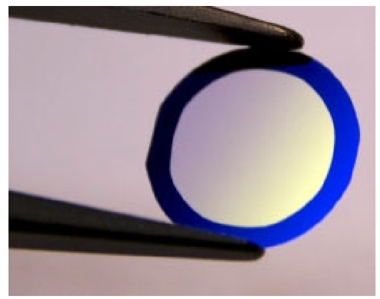


* FN: Facial Nerve

There is therefore a need for continuous IONM for MI-RCI

Structured multilayer stacks

- Coating requirements:
  - → *Hard, wear resistant*
  - → *Biocompatible*
  - → *Appropriate electrical properties*



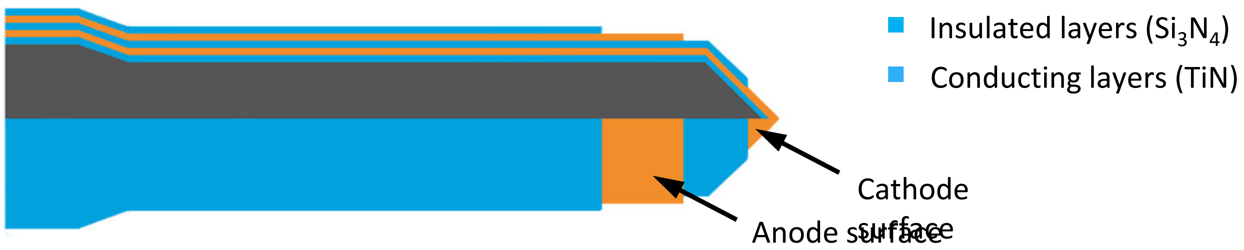
- Candidate coatings:

→ titanium nitride (TiN) for electrode surfaces

→ silicon nitride (Si_3N_4) for insulator surfaces

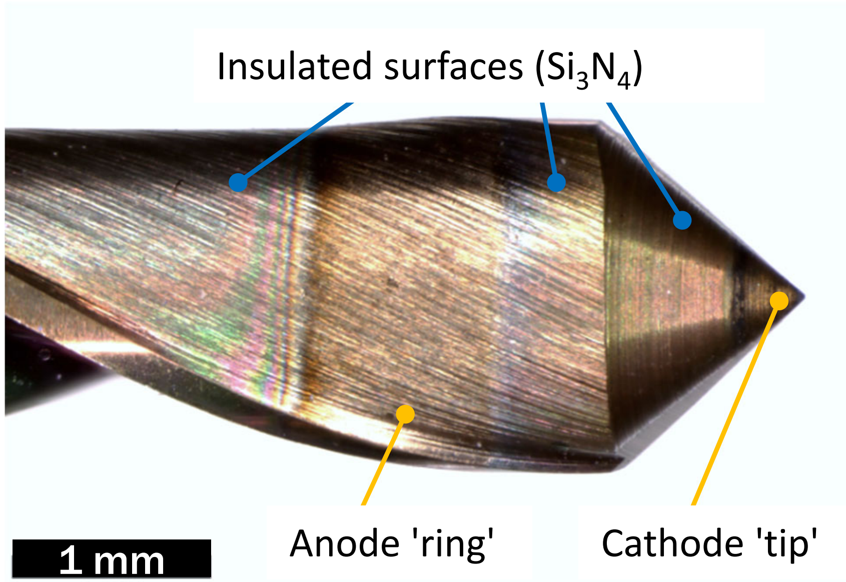
- Structured multilayered stack:

→ to mimic ring and cone electrodes on the drill bit



Drill-integrated electrodes

Structured multilayer stacks by Reactive magnetron sputtering



Solid State Calibration Target for Fluorescence Microscopy

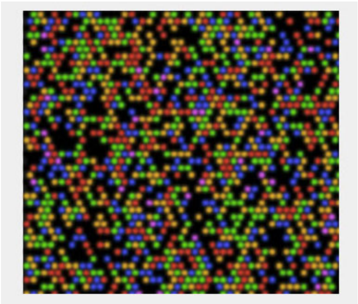
History of DNA sequencers

Till 2000s:

First human genome sequence completed
(after 13 years in 2003)

Present day:

State of the art: 64 human genomes per day
(sequence 2 trillion DNA bases per slide)

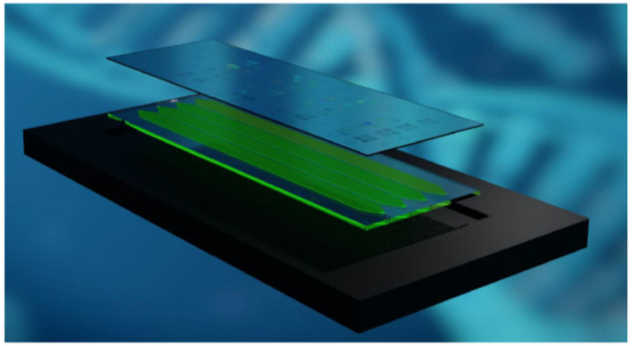


- Fluorescence microscopes are an integral part of DNA sequencing
- There is a high demand for *high lateral resolution microscopes* (nm scale) with fast processing.

https://www.genome.gov/genetics-glossary/DNA-Sequencing

Calibration targets

- **Fluorescence microscope needs calibration**
- **Calibration target**
  - Microscope needs to calibrated with a reference structure called calibration target
  - This device has a photoluominescent (PL) layer capable of being excited by laser ligh



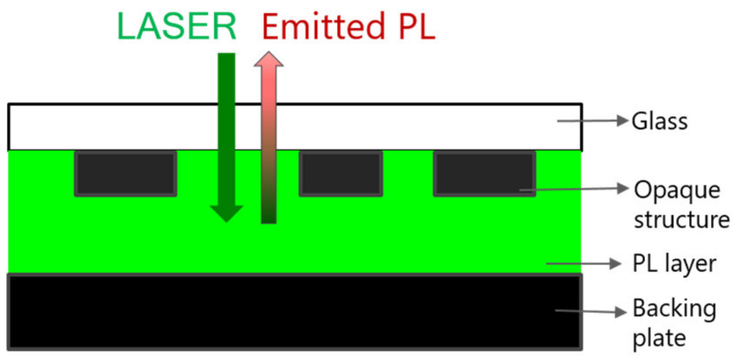
A commercial calibration target based on liquid dye

Available fluorescent materials	Issues
Fluorescent dyes like fluorescein	▪ Not stable PL on repeated exposure to light ▪ Needs channels to confine the liquid ▪ Hard to make liquid bubble-free in channels
Fluorescent glass	▪ Low-volume speciality, not available in top quality ▪ Non-uniform rough surface → limited resolution ▪ Emitted PL is not broadband

State of the Art

What is required

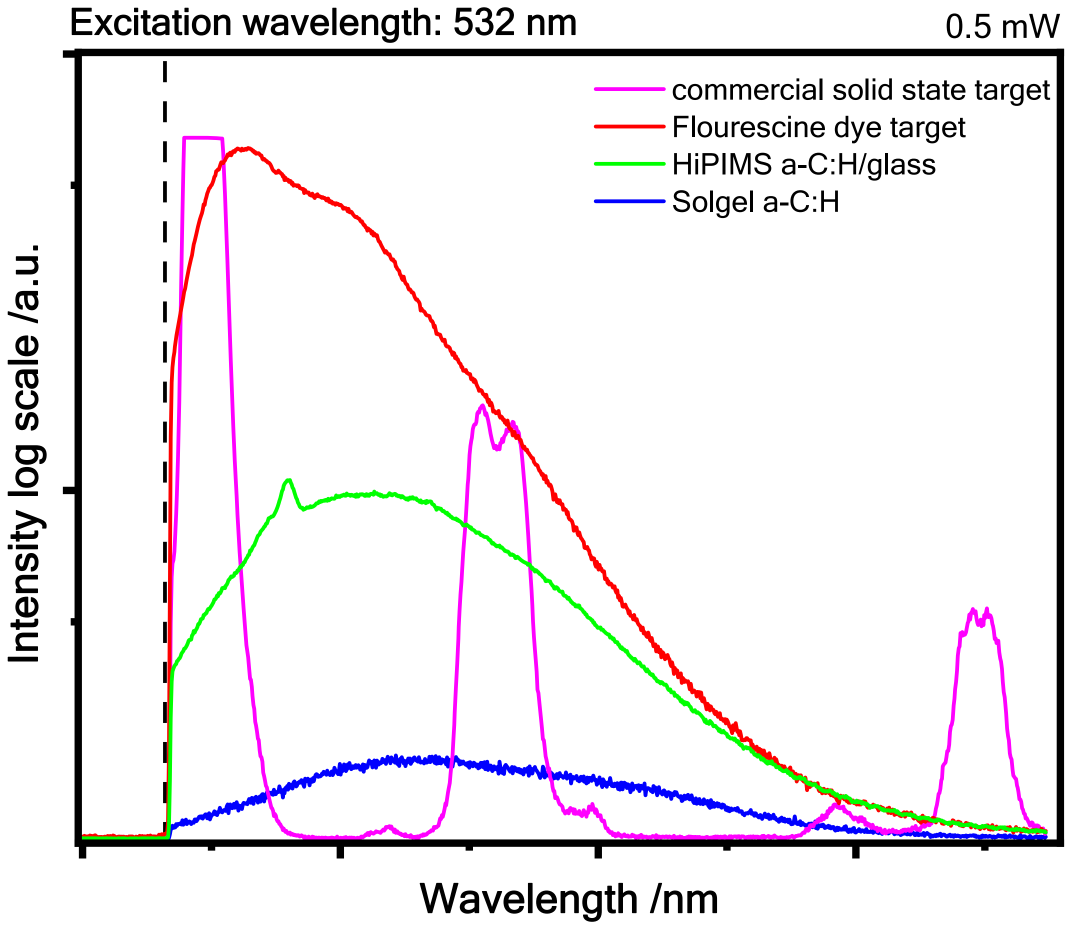
- Broadband spectra of emission for visible light
- Stable under repeated exposure to W/mm^2 LASER irradiation
- High lateral resolution therefore highly homogeneous at sub-µm scale



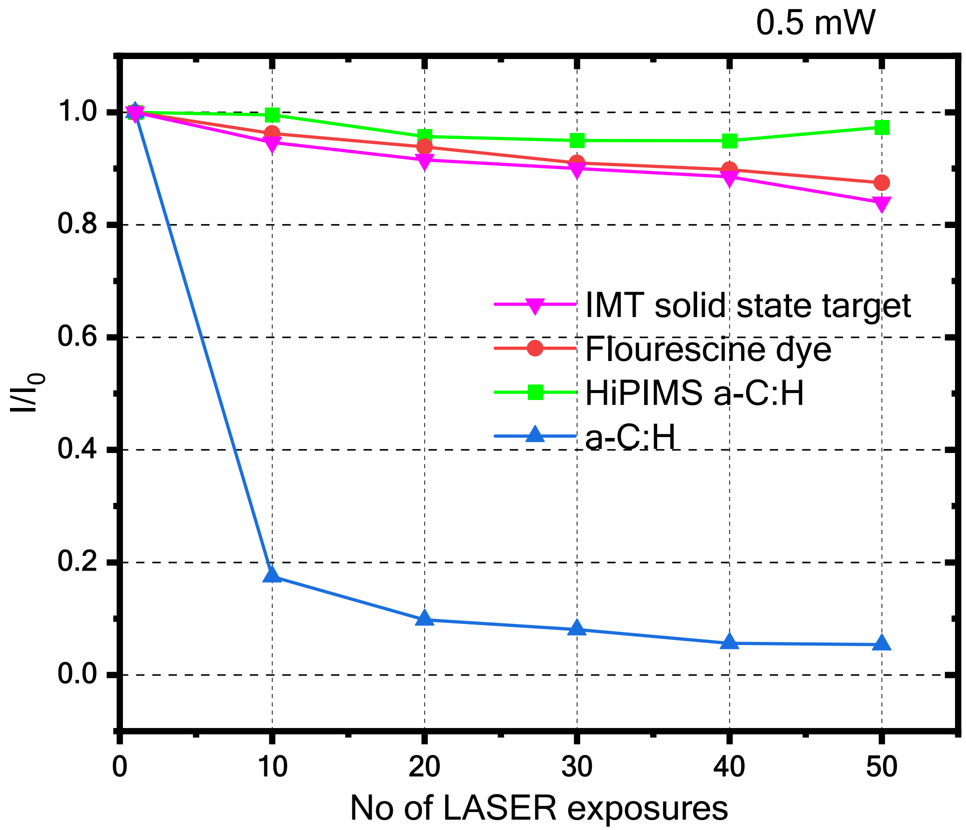
Schematic representation of a calibration target [1]

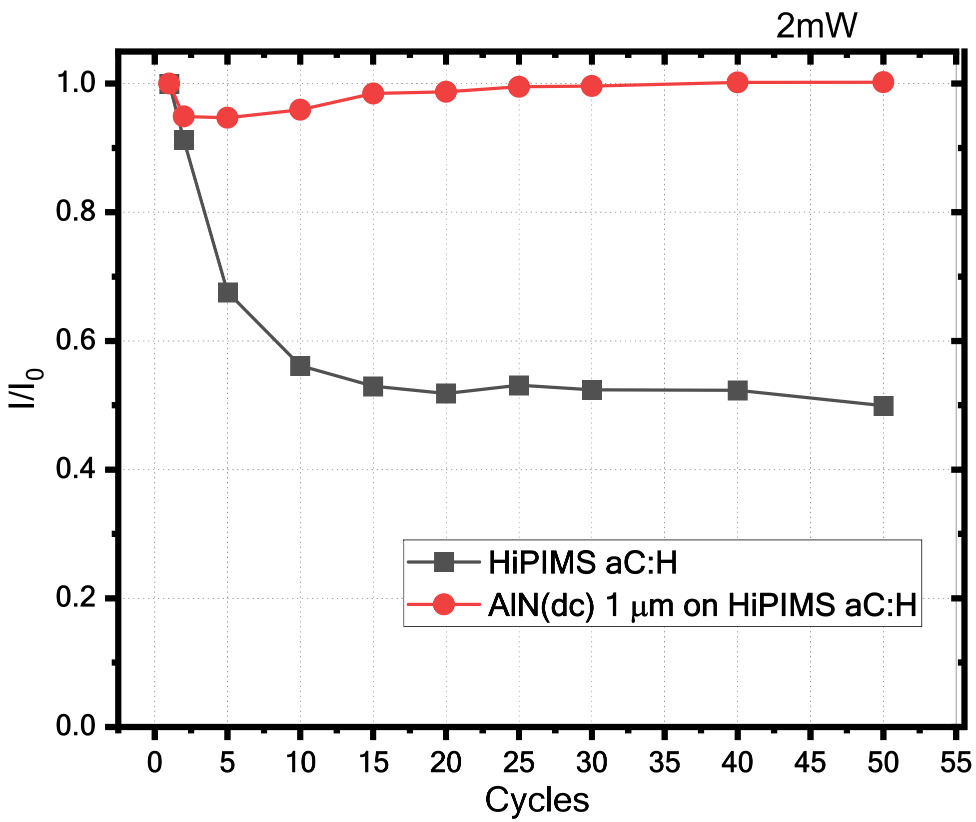
[1] Thorwarth, Calibration target, US Patent 1,543,350, 2023.

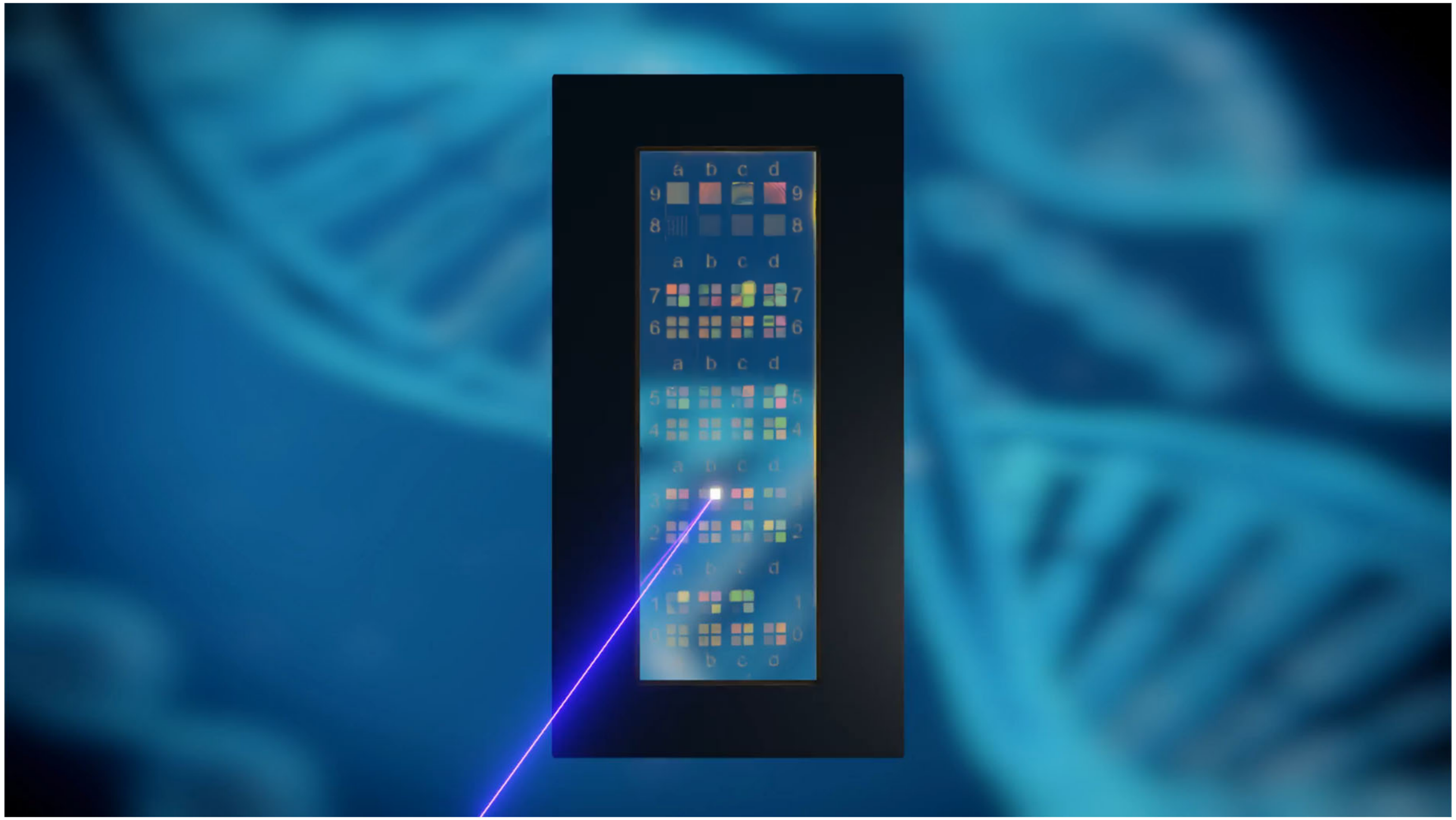
Comparison of amorphous carbon with PL material used in commercial target



PL intensity loss with repeated exposure to LASER



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+41 58 765 11 11
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