The iPhone 5

Alternatives for the glass screen

iTeam

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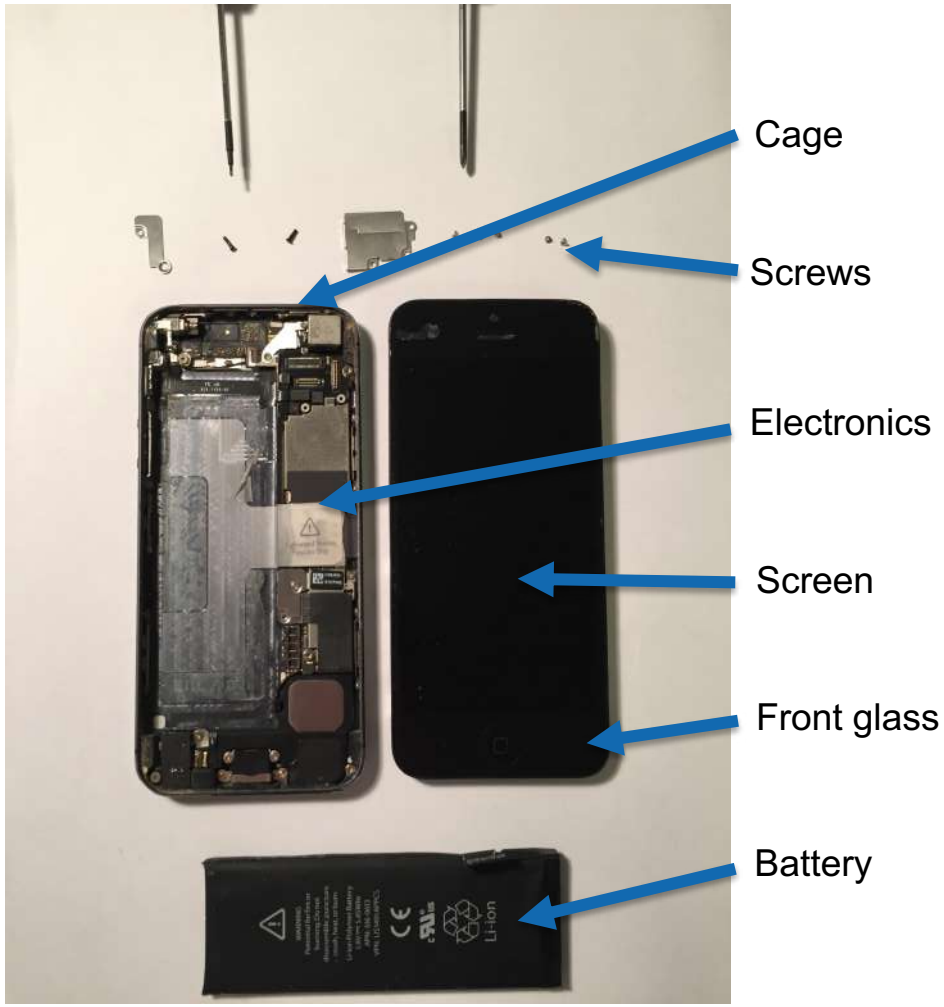
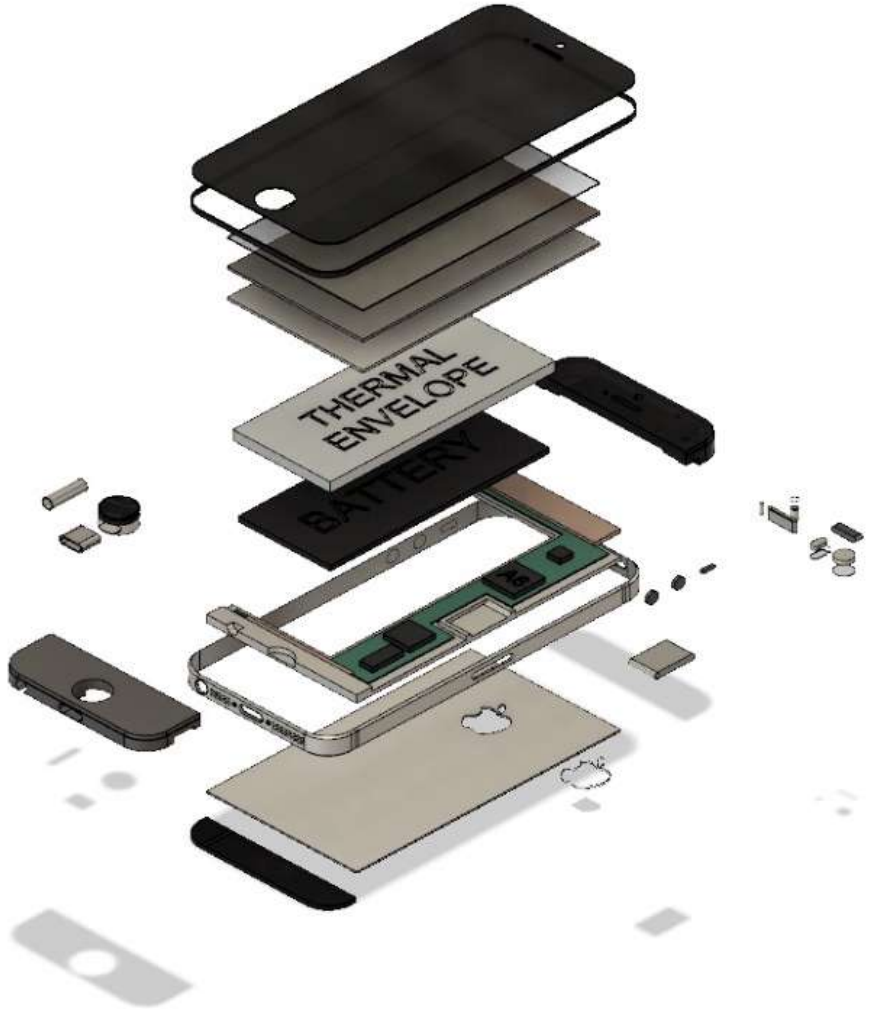
Product Characterization – Workflow

- Disassembly → a lot of very different parts
- Decision to focus on screen, its composition and mechanical properties
- Cutting the screen with a diamond saw
- Microsection → first overview of components
- Indentation → to investigate hardness
- Differential Scanning Calorimetry (DSC) → thermal properties to identify material
- Scanning Electron Microscopy (SEM) with Energy-dispersive X-ray spectroscopy (EDS, EDX, EDXS or XEDS) → is there a K gradient? Is it really Gorilla Glass
- Literature research of used material and alternative materials for mechanical properties and environmental impact
- Simulation to compare used material with selected alternatives

What’s inside





iPhone 5

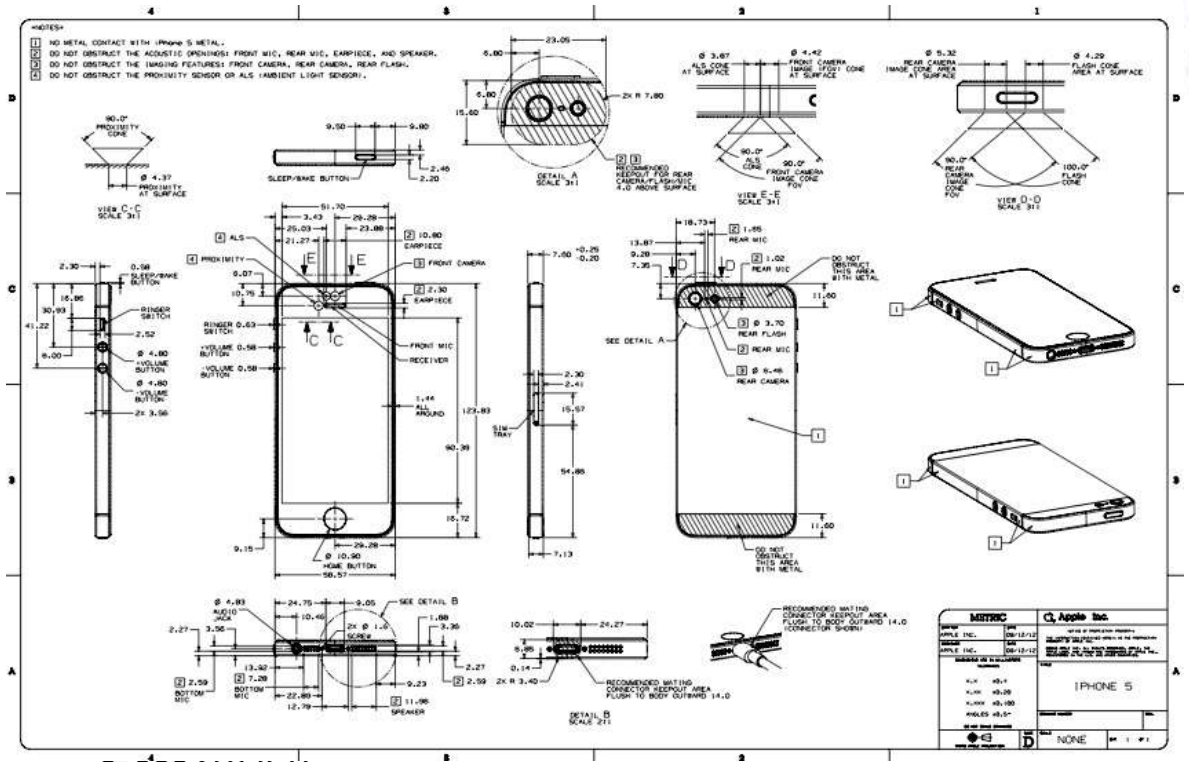
- The iPhone 5 is an object intended to be used with one or both hands and carried with (inside a pocket or a purse, for example) every day.

- For these reasons the iPhone 5 must be designed to resists scratches and impacts, but also to be nice to the eyes and pleasant to the touch.

- In this respect, the front of the phone, where the screen is located, the most used and watched part of the whole object, is of fundamental importance.

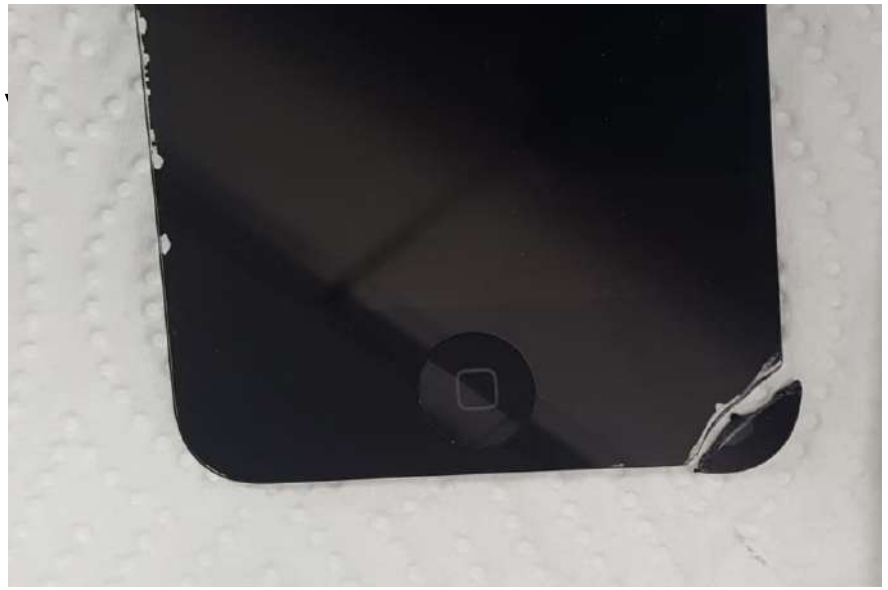
The iPhone 5

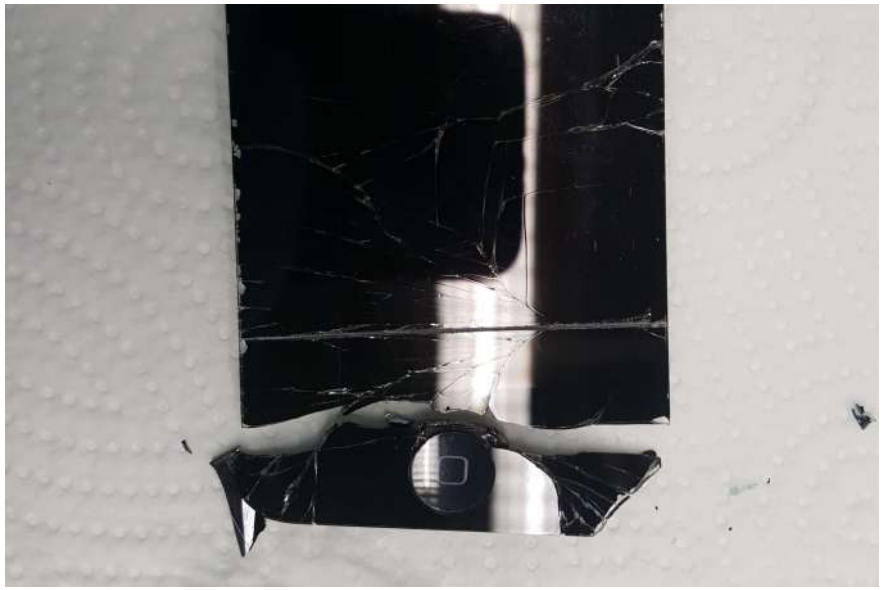
- Introduced in 2012



Preparing for material anal

- The probes have to fit in the instruments



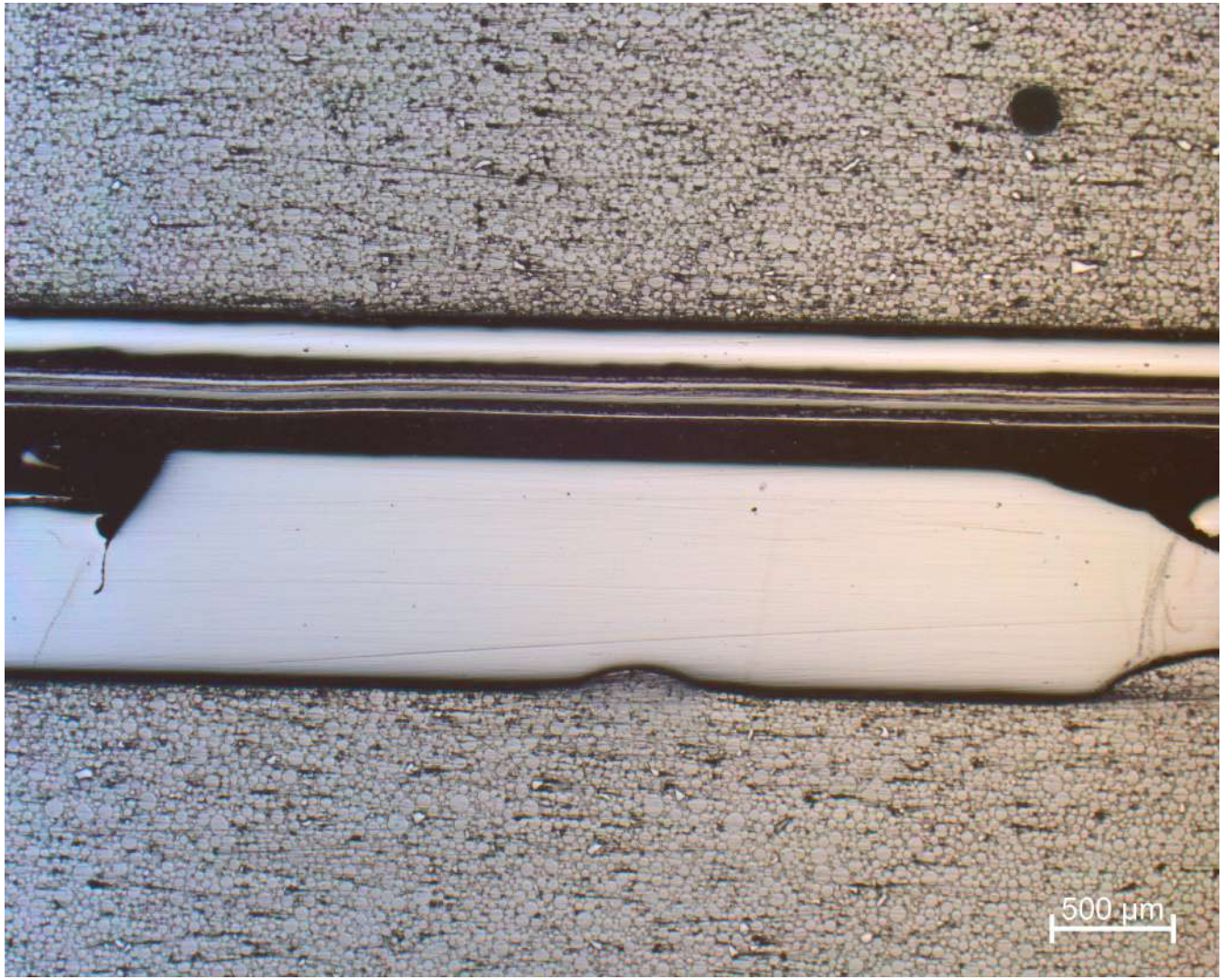


Screen disassembly

sources

- https://cdn.preis.de/p/3272128/450x450/85/1/Apple-iPhone-5S-16GB-Spacegrau-ohne-Vertrag-1494491980457.jpg
- https://de.wikipedia.org/wiki/IPhone_5
- https://vkrepair.com/wp-content/uploads/2015/07/iphone-5-parts-diagram.jpg
- https://mms.businesswire.com/media/20160404005764/en/517260/5/Exploded_View.jpg?download=1
- https://images-wixmp-ed30a86b8c4ca887773594c2.wixmp.com/f/1ce6fc1e-955e-4043-a8ea-a86ac6161aea/d5encd1-291d0ab8-0551-47c3-9db5-2f65178ac4b0.jpg/v1/fill/w_900,h_507,q_75,strp/it_s_finally_here__iphone_5_by_mauriziocorso77_d5encd1-fullview.jpg?token=eyJ0eXAiOiJKV1QiLCJhbGciOiJIUzI1NiJ9.eyJzdWIiOiJ1cm46YXBwOiIsImlzcyI6InVybjphcHA6Iiwib2JqIjpbW3siaGVpZ2h0IjoiPD01MDciLCJwYXRoIjoiXC9mXC8xY2U2ZmMxZS05NTViLTQwNDMtYThlYS1hODZhYzYxNjFhZWFcL2Q1ZW5jZDEtMjkxZDBhYjgtMDU1MS00N2MzLTlkYjUtMmY2NTE3OGFjNGIwLmpwZyIsIndpZHRoIjoiPD05MDAifV1dLCJhdWQiOlsidXJuOnNlcnZpY2U6aW1hZ2Uub3BlcmF0aW9ucyJdfQ.9t_0FkFEZrhBh75XdE_Z0Lpacc5d2v2XgPaZ62SWsUM

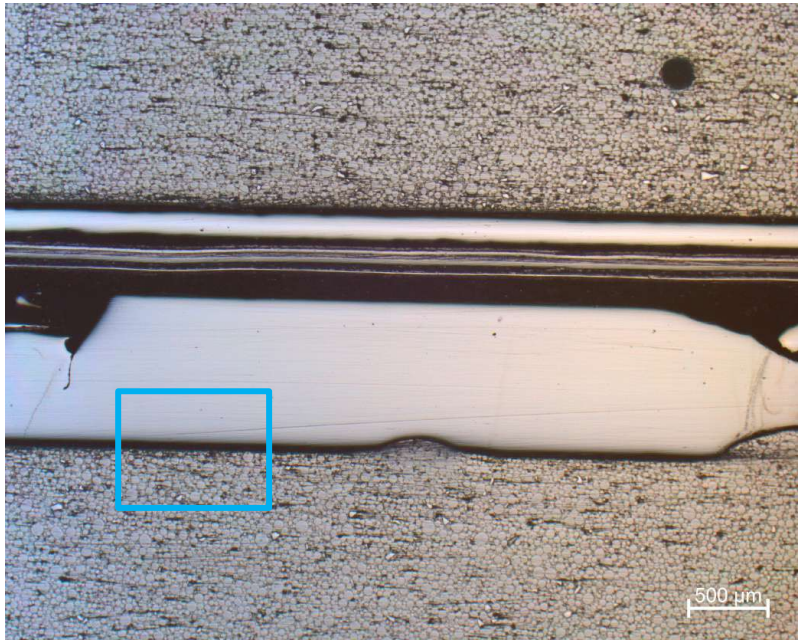
Microsection



Display

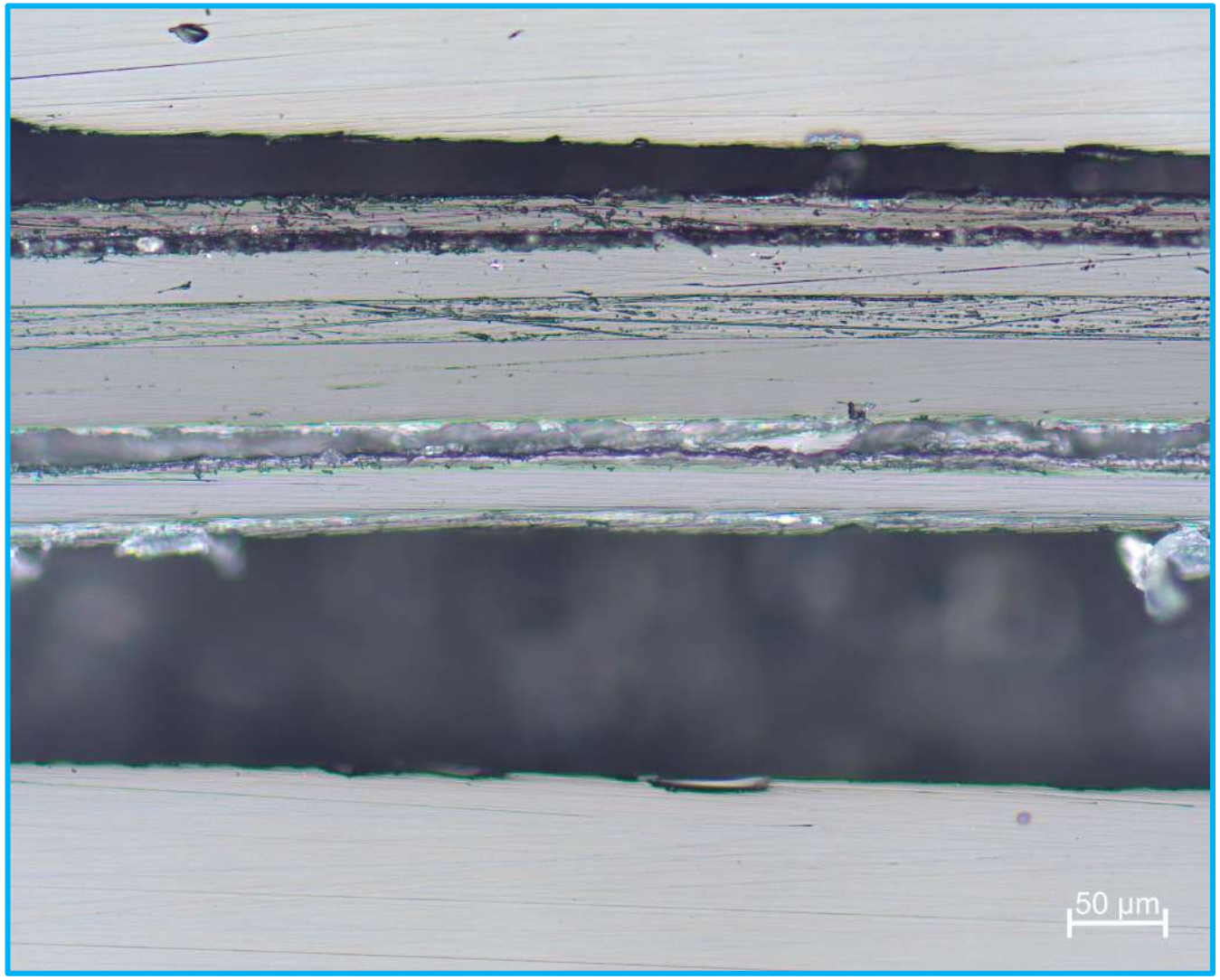
Glass, thickness = 1mm

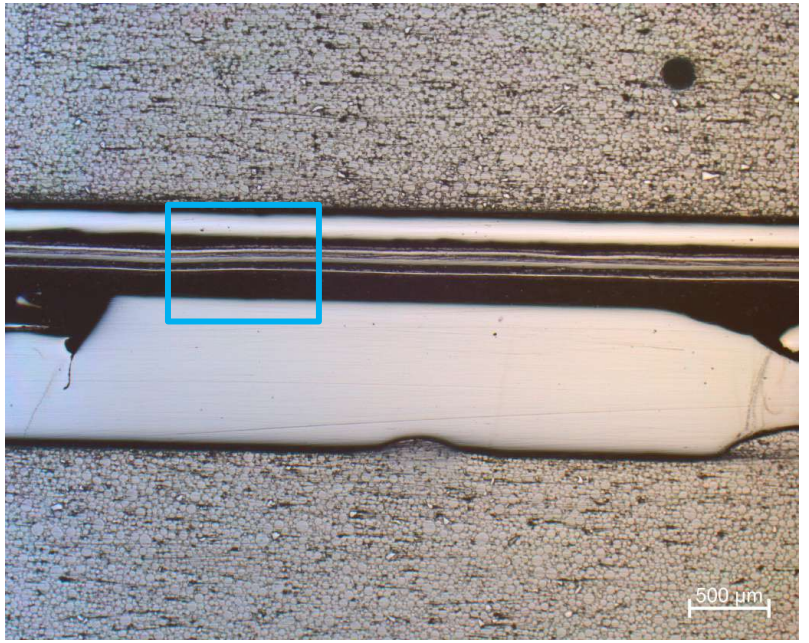
Microsection



No indication for a polymeric film on glass surface

Microsection





Gaps inbetween layers caused by cutting

Gorilla Glass

- Almost all of the front surface of the iPhone 5 is covered by a particular glass called Gorilla Glass.

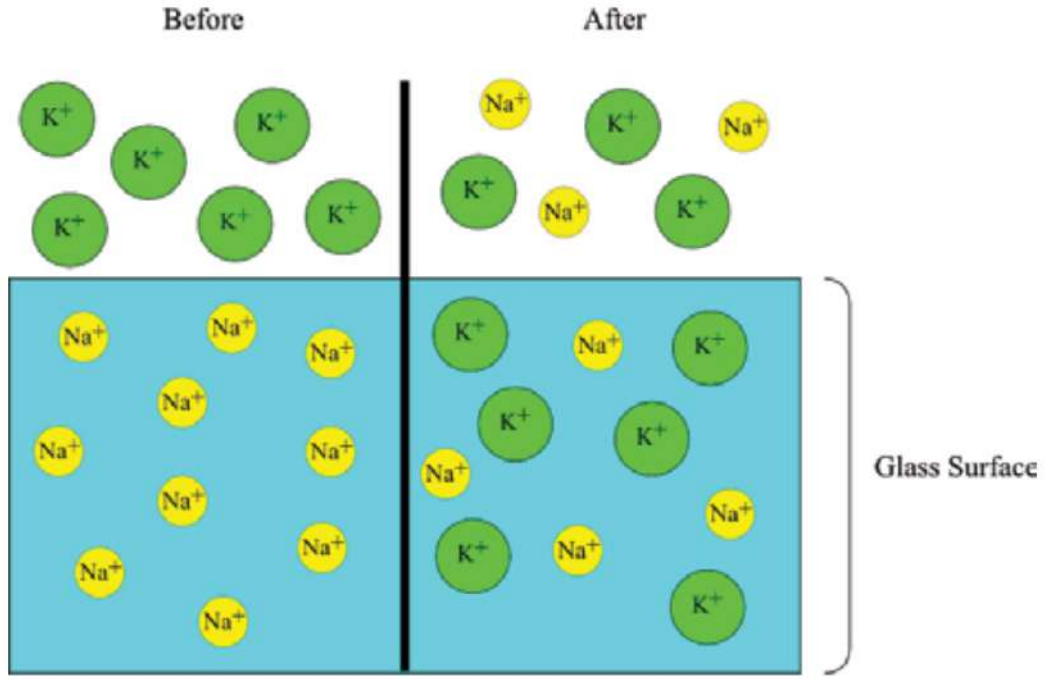
- The Gorilla Glass is made of a material named alkali-aluminosilicate glass, formed by bonding chemically aluminium, silicone and oxygen together.

- The glass gains its surface strength with the ion exchange of potassium and sodium, providing high scratch-resistance and hardness. It can be thin without being fragile.

Ion exchange

- The ion exchange takes place in a hot tub bath of molten salt at a temperature of approximately 400°C. Smaller sodium ions leave the glass and are replaced by larger potassium ions from the salt bath.

- Potassium ions take up more space and are pressed together when the glass cools down, producing a layer of compressive stress on the surface of the glass, resulting in a surface more resistant to damage.



Gorilla Glass

- Gorilla Glass is developed and manufactured by Corning, an American technology company, and it was brought into commercial use when the first iPhone came out.

- The technology of the Gorilla Glass of the iPhone 5 is of second generation, Gorilla Glass 2, and it is just as resistant but 20% thinner than the original model, in this way, a greater sensitivity to the user's touch and an excellent feeling can be guaranteed.

- As of today there are seven generations of Gorilla Glass, with the last one called Gorilla Glass Victus. Generation after generation they developed glasses more resistant to scratches and especially to drops.

Product characterization - Indentation

CORNING Gorilla® Glass

Product Information

Vickers Hardness (200g load)

Unstrengthened	534 kgf/mm^2
Strengthened	649 kgf/mm^2

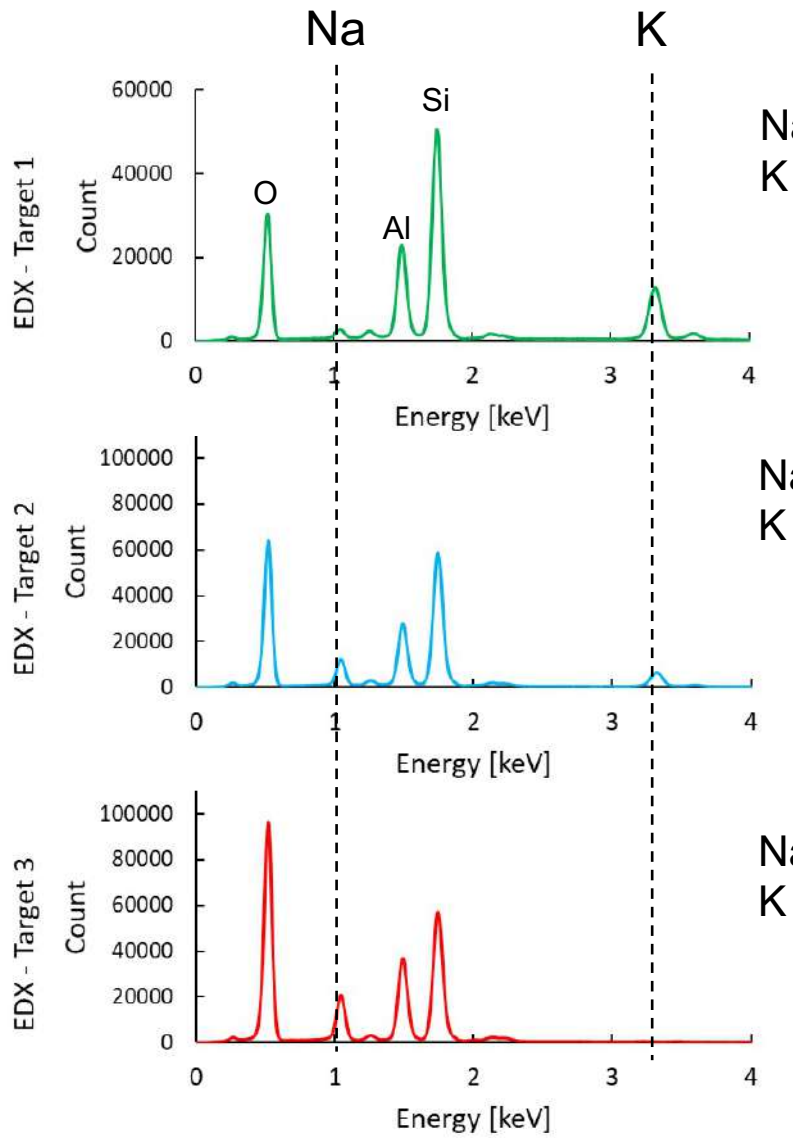
iTeam

Our Result (95%, 10 Measurements)

Vickers Hardness (3 kg load)

607 ± 9 kgf/mm^2

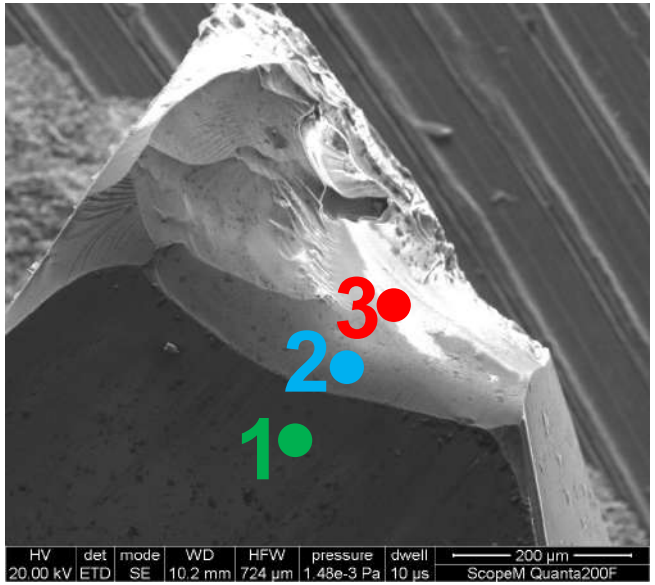
Product characterization – Chemical Analysis



Na 2.27 at. %
K 6.71 at. %

Na 7.52 at. %
K 2.21 at. %

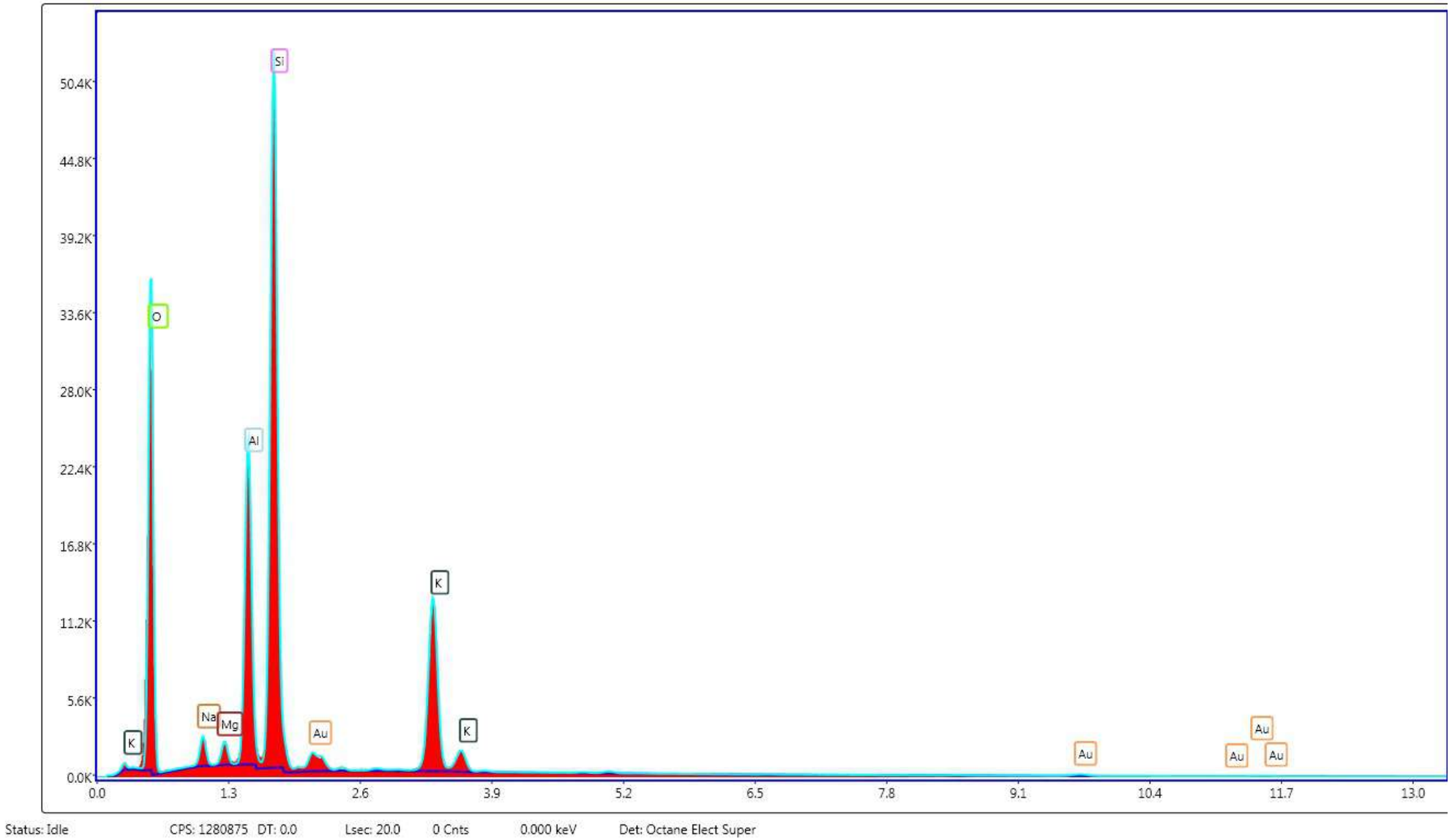
Na 9.3 at. %
K undetected



- The chemical analysis revealed the presence of K on the surface of the glass
- As the measurement is conducted deeper inside the glass K is substituted by Na

- **No K detected in the middle (Target 3)**
- **Ion exchange toughened aluminosilicate glass**

EDX on surface

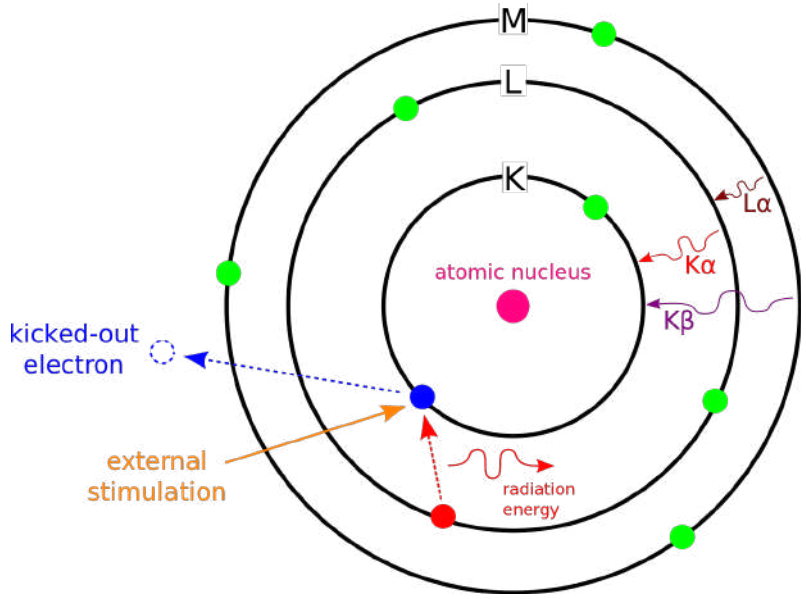


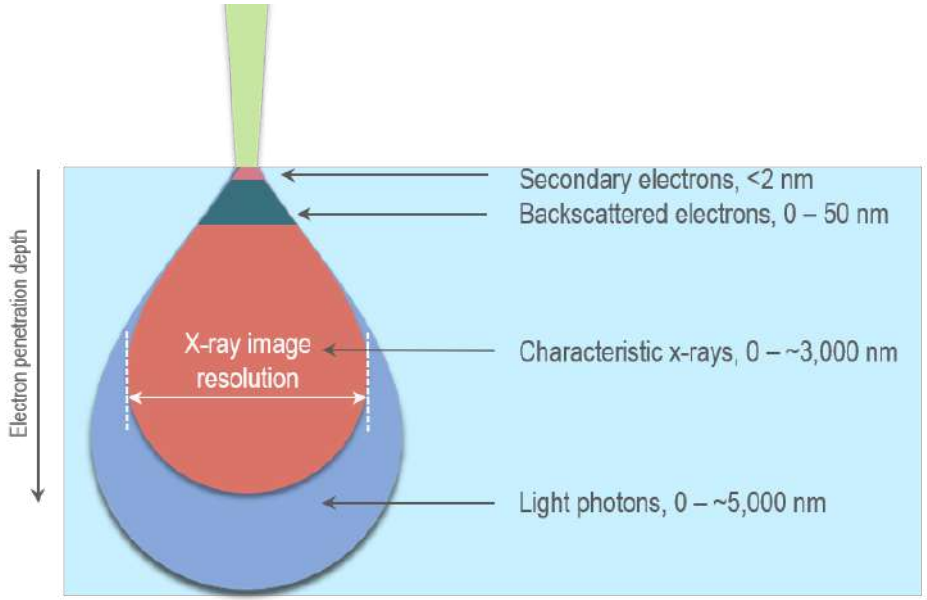
EDX Spectroscopy

- Energy-dispersive X-ray spectroscopy (EDS, EDX, EDXS or XEDS), is an analytical technique used for the elemental analysis or chemical characterization of a sample.

- In this case an e beam is focused on the sample which will excite electrons from an inner to an outer shell. As result electron will go back to ground state emitting a characteristic X-Ray spectrum.

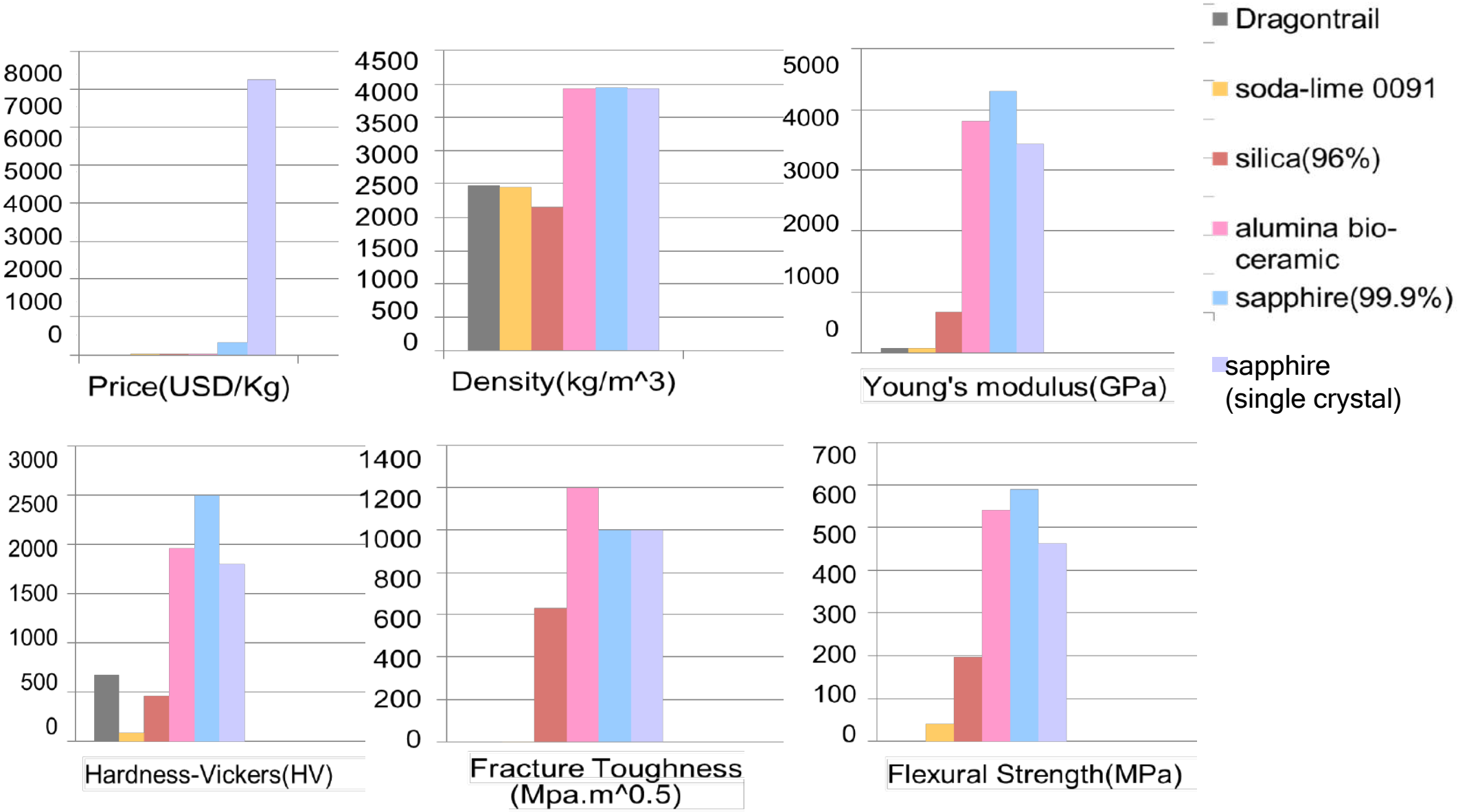
- The penetration depth of the electrons that cause the characteristic emission depends on their energy.
- At 20 keV we are around 500 nm in depth.





In Search of Alternative Materials

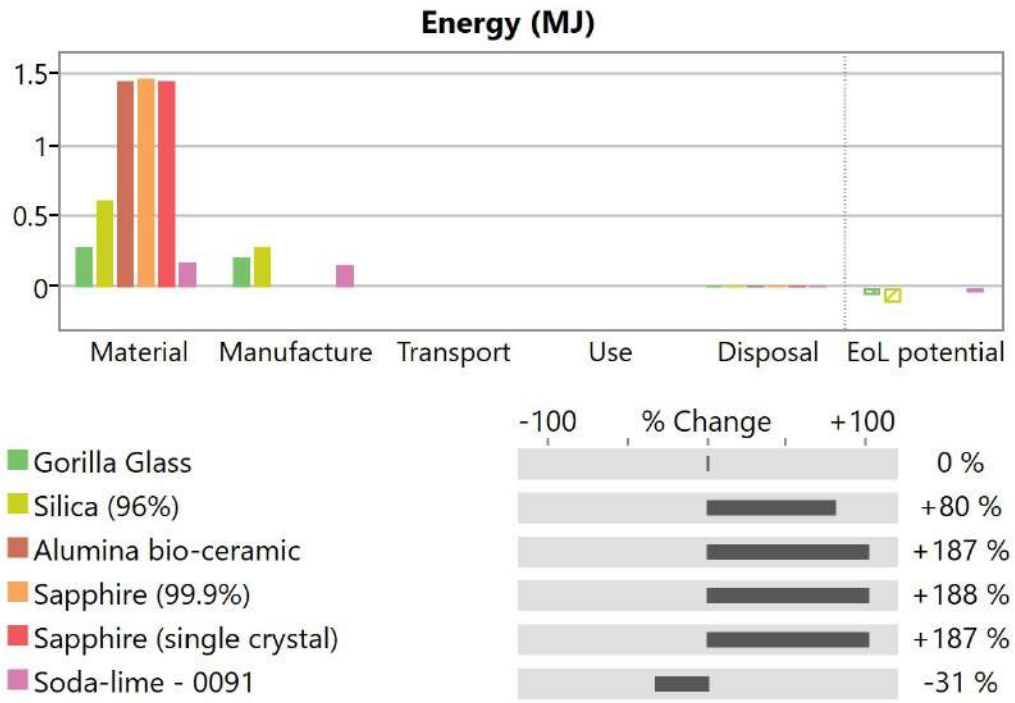
- Dragontrail
- Soda-lime 0091
- Silica (96%)
- Aluminum Bio-Ceramic
- Sapphire (99.9%)
- Sapphire (single-crystal)

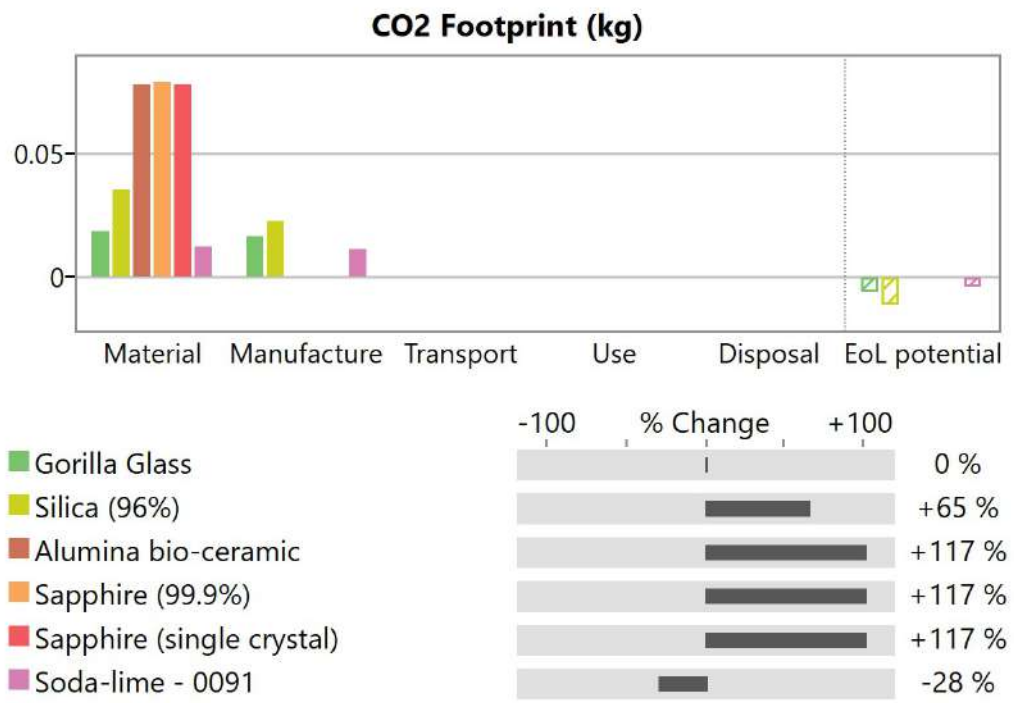


(All the data above comes from CES Edupack database or directly from AGC company)

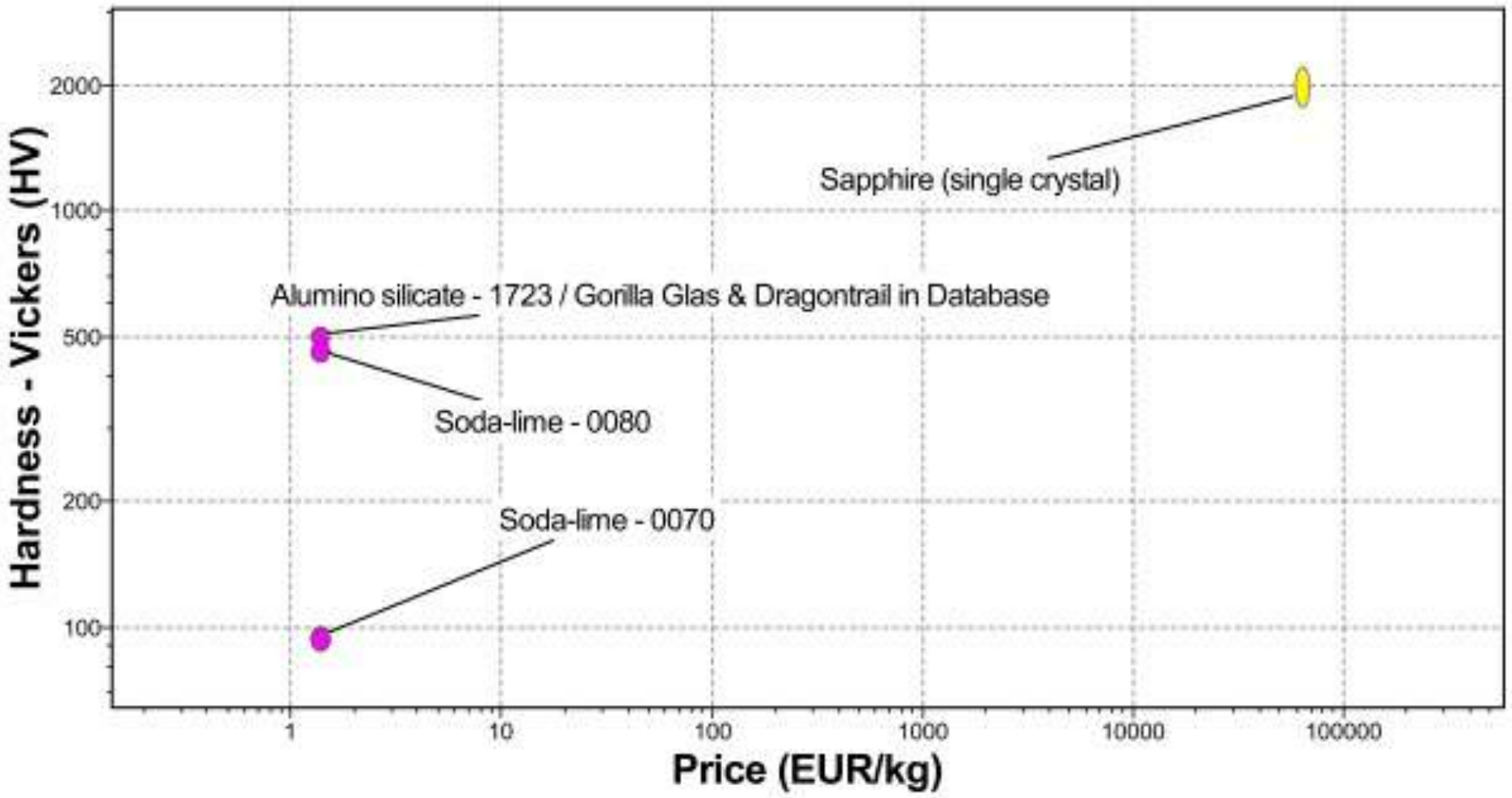
	Soda-lime 0091	Silica(96%)	Aluminum bio-ceramic	Sapphire (99.9%)	Sapphire (single crystal)
Production CO_2 Footprint(kg/kg)	0.72	2.25	2.67	2.67	2.67
Water Usage(L/kg)	13.4	2.96	55.6	55.7	55.7
Process CO_2 Molding Footprint(kg/kg)	0.67	1.44	/	/	/
Process CO_2 Grinding Footprint(kg/kg)	1.86	10.5	16.2	7.56	8.52
Recycle	√	√	×	×	×
Recycle Fraction (%)	22.7	23.8	/	0.672	0.672
Biodegrade	×	×	×	×	×

Eco-design comparison

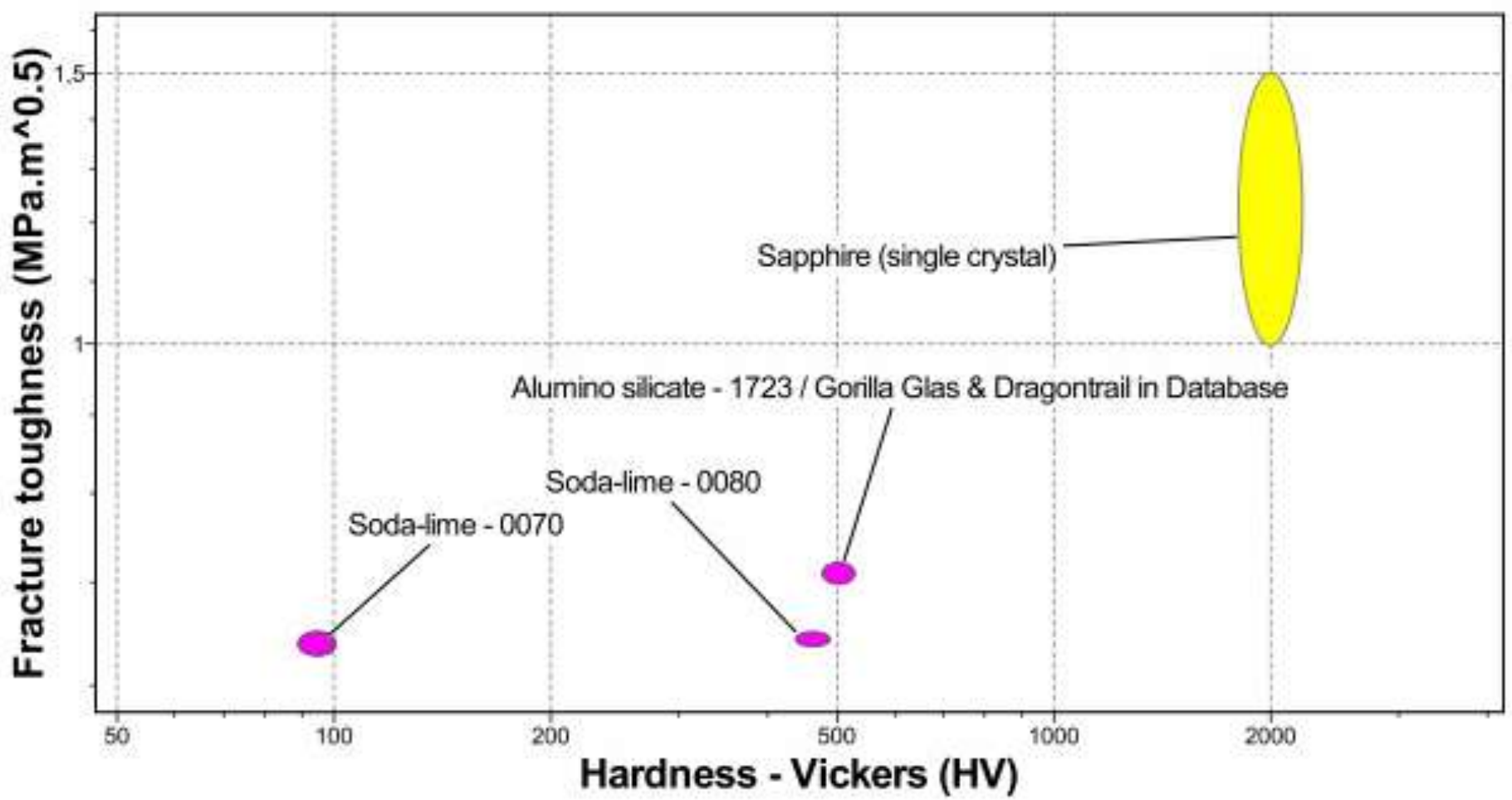




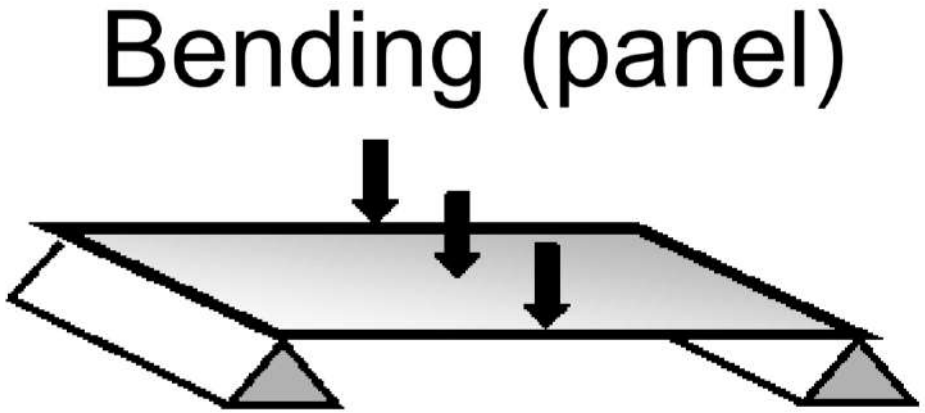
Ashby Diagrams



Ashby Diagrams



Material index



- F_f: Maximal force to failure
- L: length of the screen (fix)
- b: width of the screen (fix)
- d: thickness of the screen (free)
- ρ: Density
- σ_y: Strength of the material

Strength: $\sigma_y = F_f \cdot \frac{3L}{2bd^2}$

Mass: $m = Ldb\rho$

Thicknes as free parameter: $d = \sqrt{F_f \cdot \frac{3L}{\sigma_y 2b}}$

Minimize mass: $m = Lb\rho\sqrt{F_f \cdot \frac{3L}{\sigma_y 2b}}$

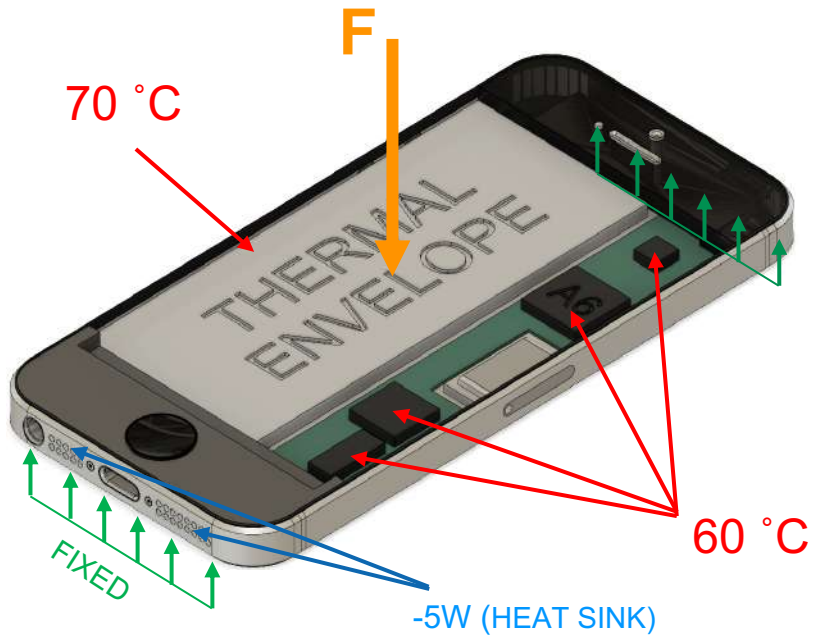
$= \sqrt{3F_f}L^{\frac{3}{2}}b \cdot \left(\frac{\rho}{\sqrt{\sigma_y}}\right)$

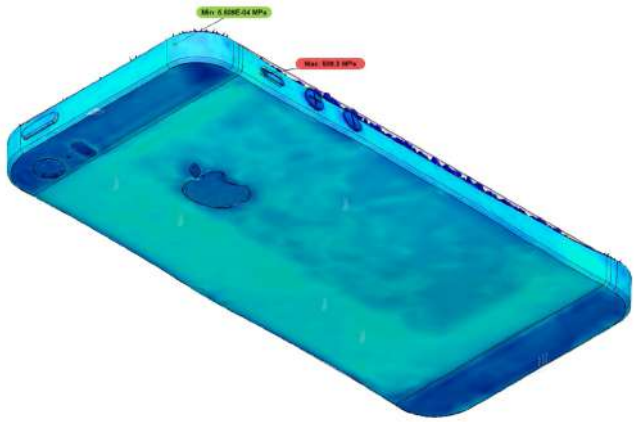
Maximize: $\left(\frac{\sqrt{\sigma_y}}{\rho}\right)$

Which alternative is best? ...CAD can help!

- A 3D CAD model of an iPhone 5 was realized.
- A simultaneous thermal-static stress simulation was performed to reproduce a bending test under extreme real-life operating conditions.

$F_{POINT\text{-}FORCE}$ = 1400 N
$T_{BATTERY}$ = 70 ˚C
$T_{ELECTRONICS}$ = 60 ˚C



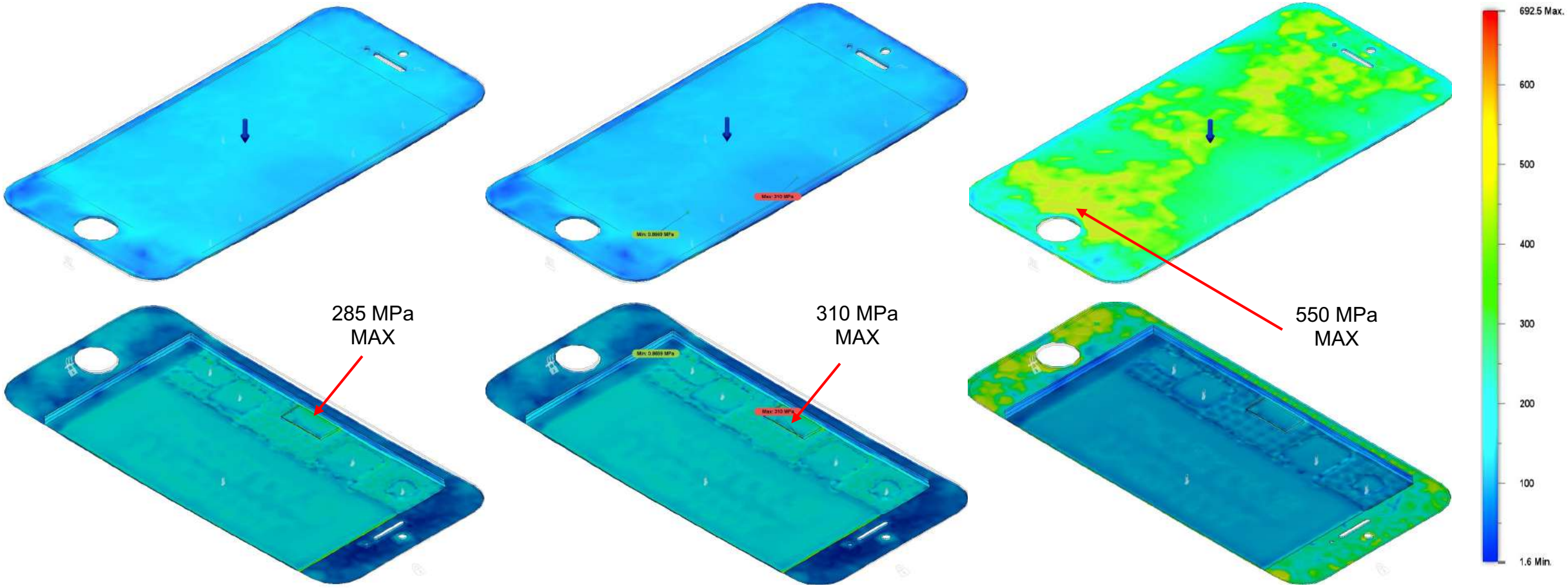


Final comparison

Gorilla® Glass [CORNING]

Soda-lime-0091

Sapphire (99.9%)



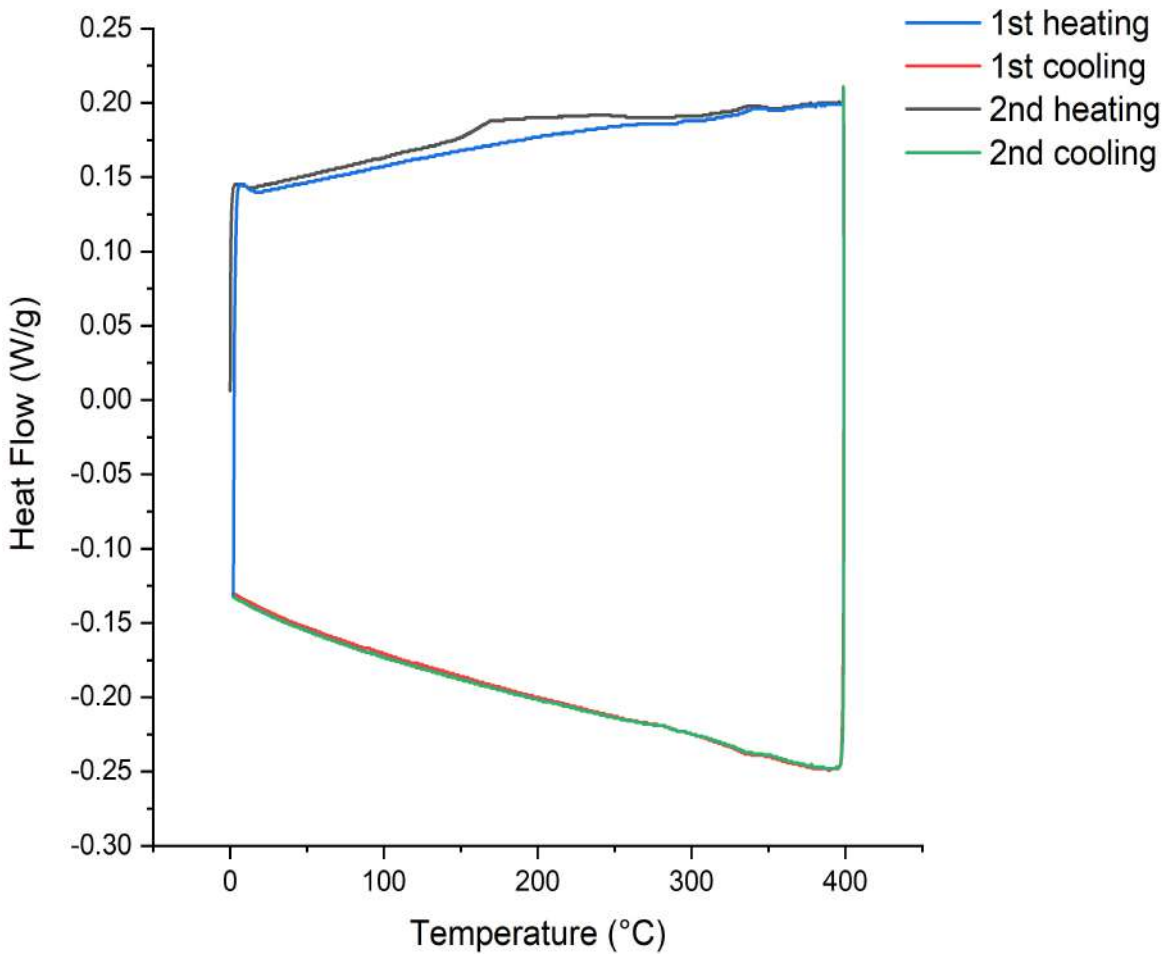
Differential scanning calorimetry (DSC)

- Differential scanning calorimetry (DSC) is a thermoanalytical technique in which the difference in the amount of heat required to increase the temperature of a sample and reference is measured as a function of temperature.

- Two heating-cooling cycles were performed between 0 ˚C to 400 ˚C with ramps of 10 ˚C/min.

- From DSC traces the isobaric specific heat capacity for Gorilla ® Glass was determined

$$C_p \approx 0.714 \text{ J g}^{-1} \text{ K}^{-1}$$



CAD simulation – Displacements and Thermal comparison

Gorilla® Glass [CORNING]

Soda-lime-0091

Sapphire (99.9%)