Glasgow/DZA collaboration towards bonding bulk silicon for a composite test mass

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3rd ET ANNUAL MEETING
MATERIALS FOR ADVANCED DETECTORS WORKSHOP
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Towards a composite mass

GOAL

Study the possibility of direct bonding several pieces of silicon to build the test mass as an alternative to large scale growth

CHALLENGES

- Intrinsic modes
- Precise bonding
- Process compatibility
- Manufacturability of bonded parts
- Strength
- Mechanical loss
- Absorption
- Scattering

PROCESSES

Hydroxide Catalysis Bonds and Direct Bonds

Content

- Context
- Status of current knowledge on bonding process
- Some recent results in Glasgow
- Next steps

Direct Bonding – manufacturability and strength

- Process comes from the semiconductor industry, mainly used with wafers (compliant samples)
- Often tested by indenting a blade to obtain bond energy – Available data not easily transferrable to bulky, structural assemblies.
- Reports that contacting properties are different when bonding bulky versus compliant samples

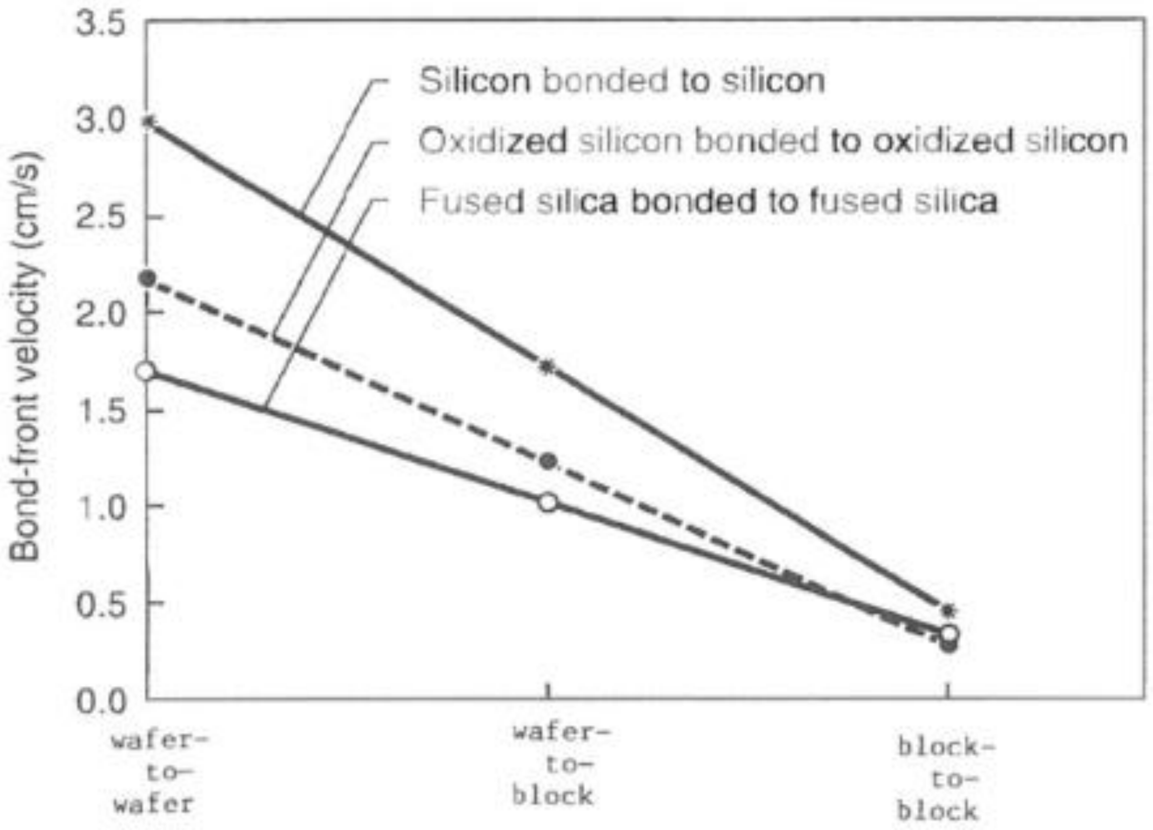


Figure 1: Velocity of contacting wave depending on part stiffness . Picture from Ref [1]

Recent results in Glasgow

- Successful direct bonding of bulky samples with standard geometry for testing
- Successful annealing at 300C (above first strengthening threshold – « LT ») and 1000C (above second strengthening threshold « HT »)
- One LT sample successfully lapped and polished, but could not be repeated
- HT samples mostly survive lapping and polishing

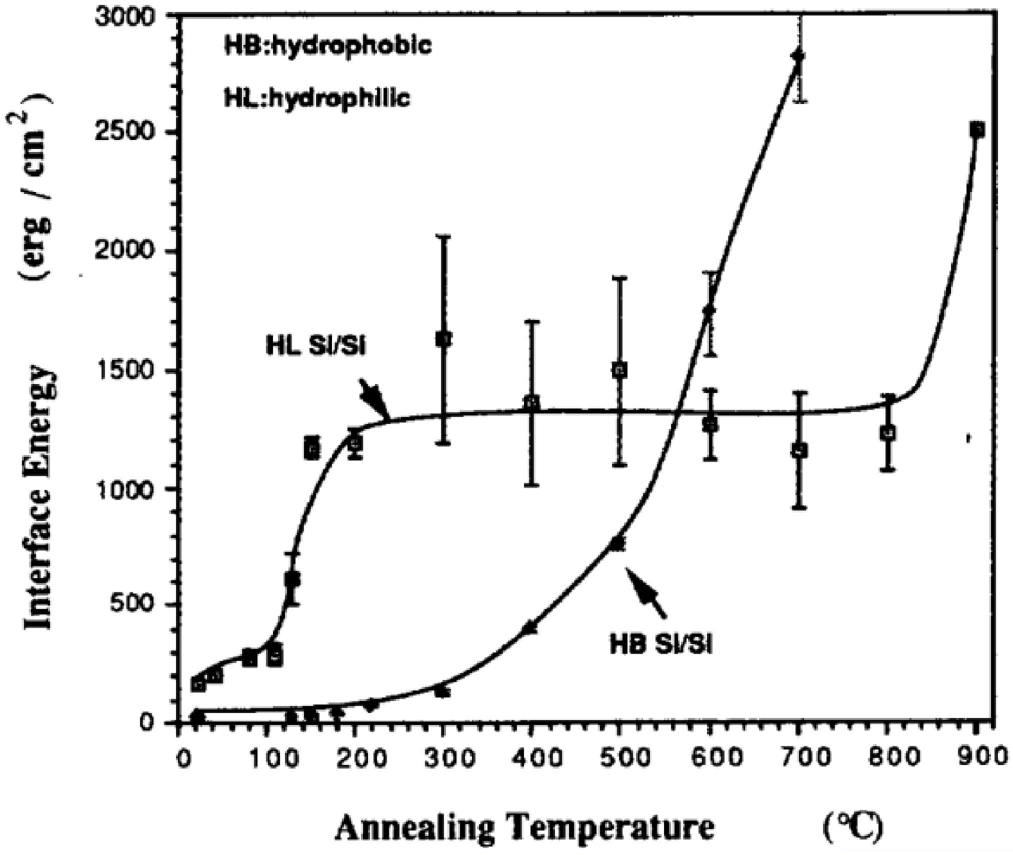
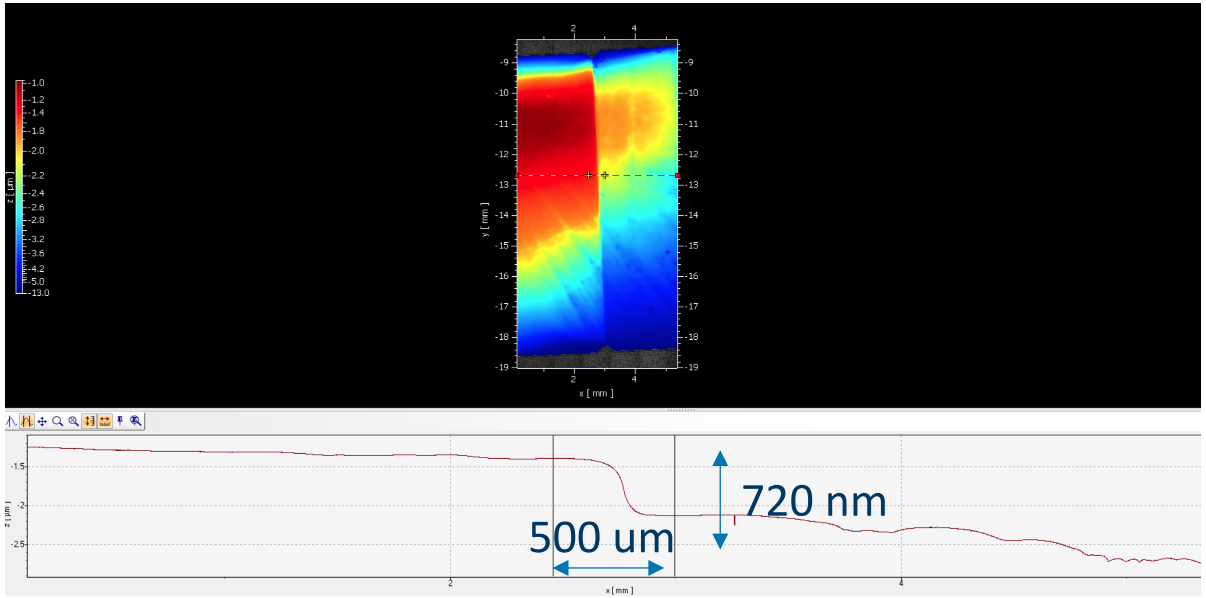
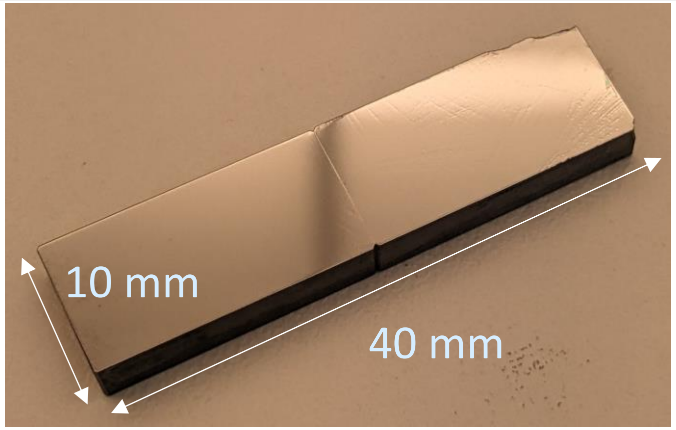


Figure 1: Bonding energy versus annealing temperature. Picture from Ref [2]

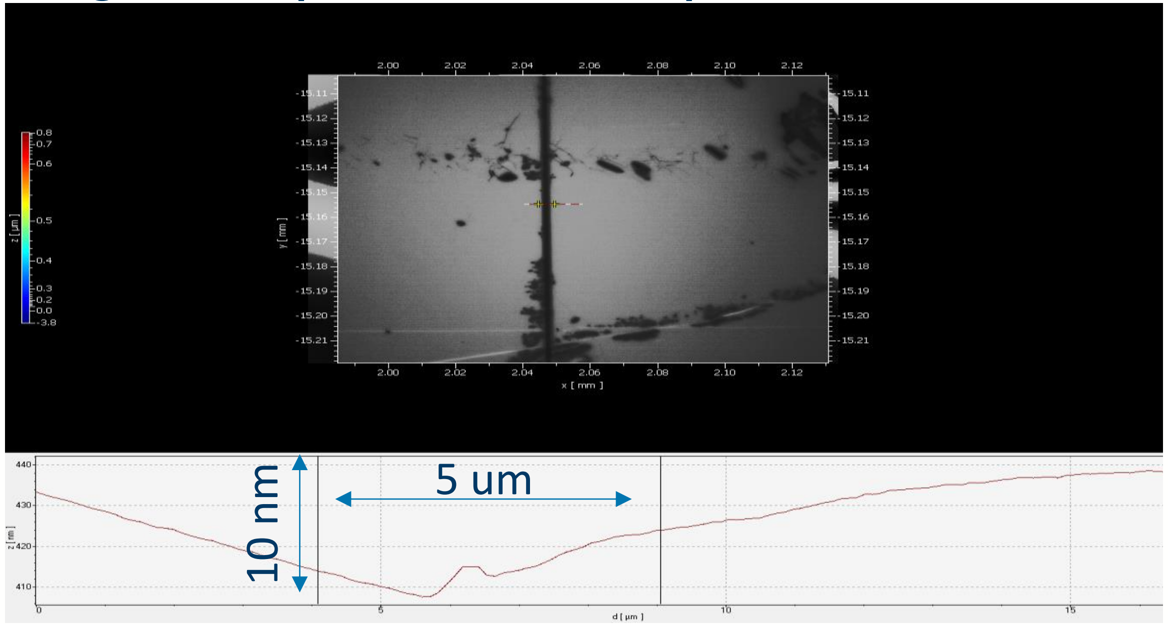
Direct bonding - Manufacturability

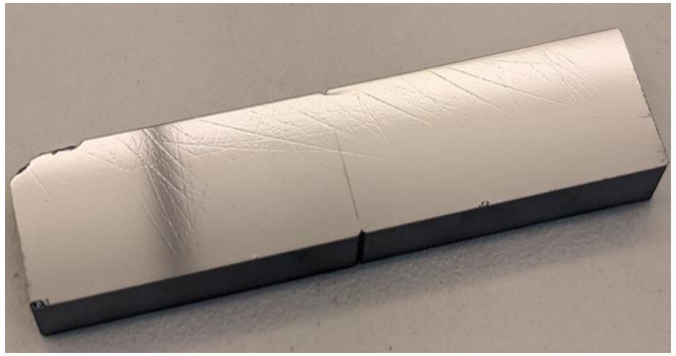
Low Temperature Sample





High Temperature Sample





4-point bending strength

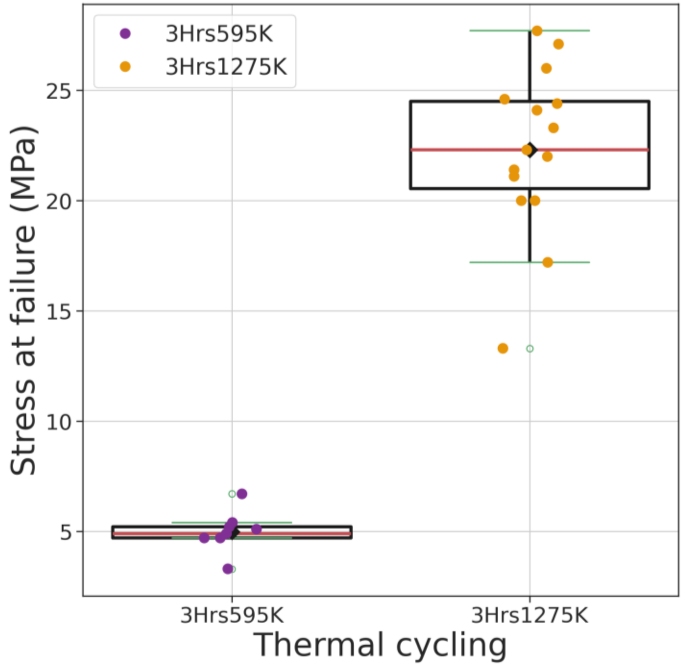


Figure1: Strength of direct bonded silicon depending on annealing temperature.

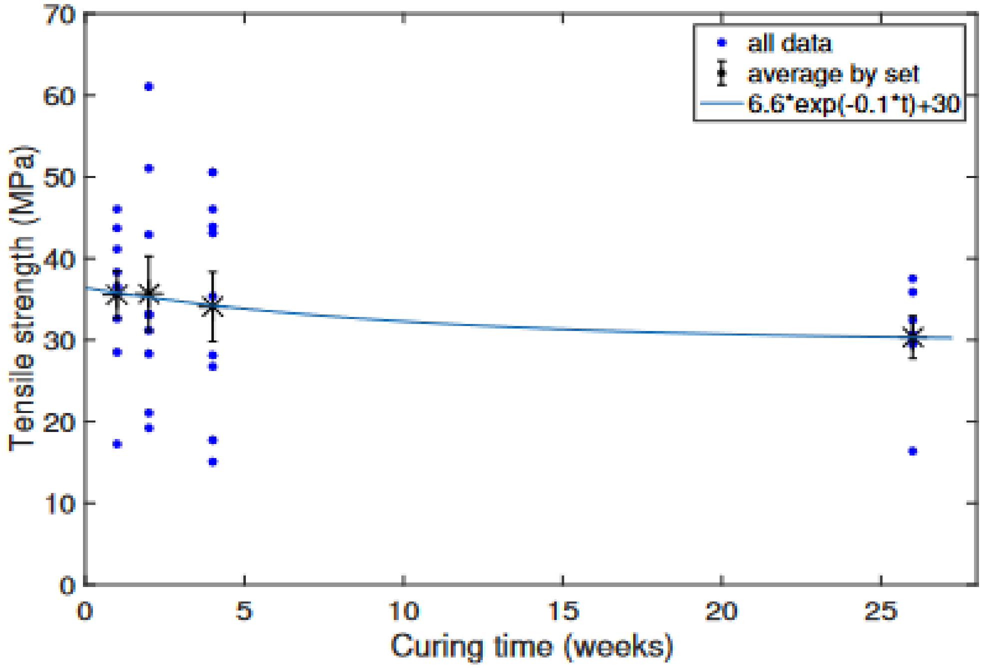


Figure2: Strength of silicate bonded (HCB) silicon over time. Picture from [3]

- Meaningful increase in strength through annealing, although still lower than HCB.
- 15MPa means 60mm^2 bonding area can hang 100kg. Area likely to be much larger so safety factor will increase.

- HCB (black) and Direct Bonded (curve 3) samples reach similar loss level at cryogenic temperature

- Bond loss not extracted

- Limited to 77K for now

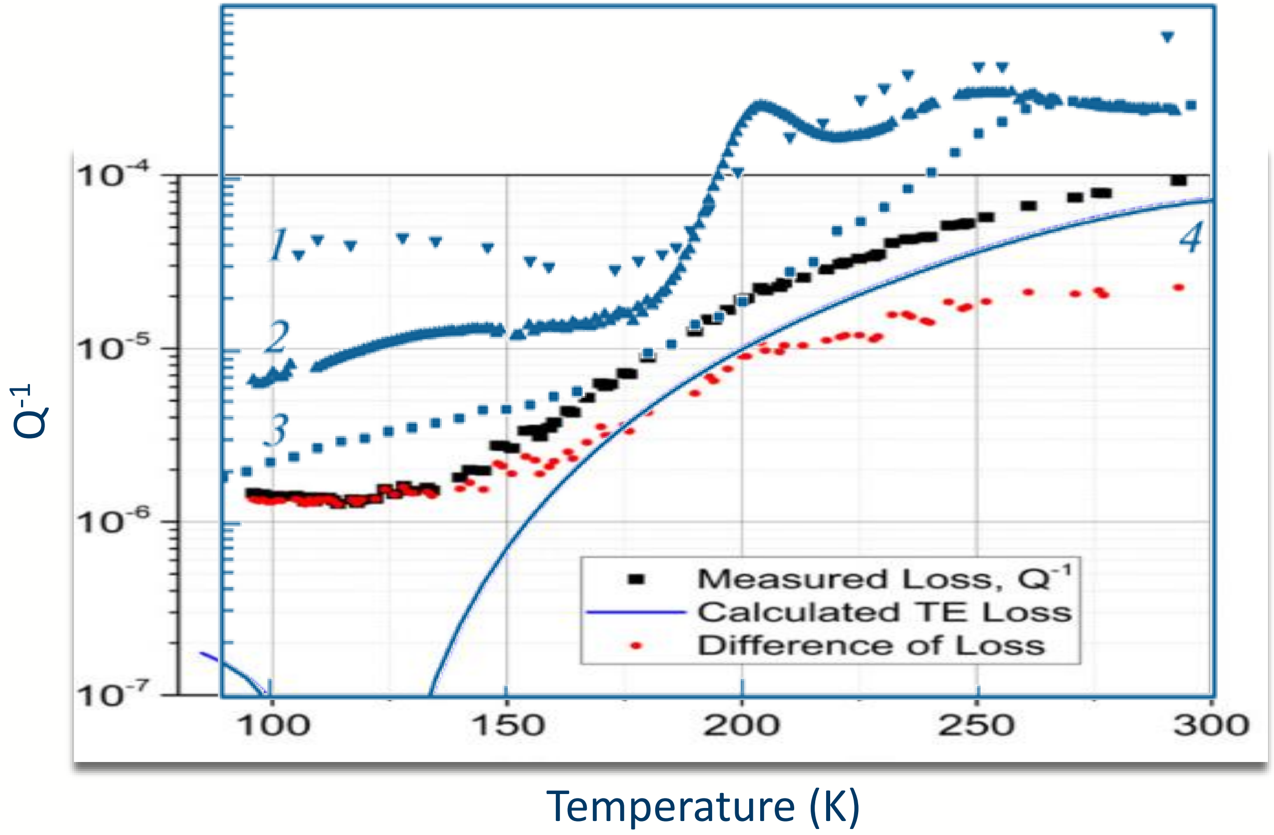


Figure1: Comparison of mechanical loss of bonded tuning fork. Direct bond in blue (curve 1,2,3 at different stages of treatment), HCB in black. Curve 4 is thermoelastic loss for both samples. Picture made from [4] and [5].

Bond Imaging

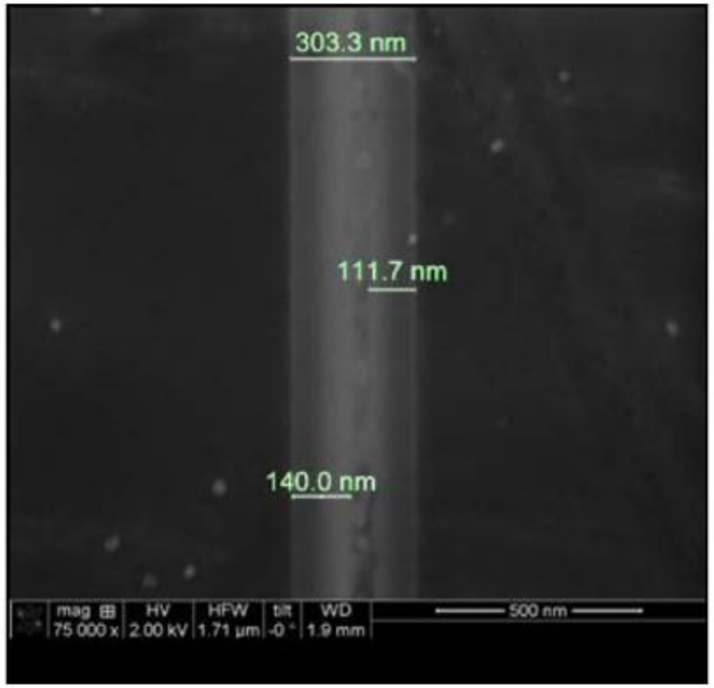


Figure1: SEM image of HCB silicon sample cross section. Picture from [6]

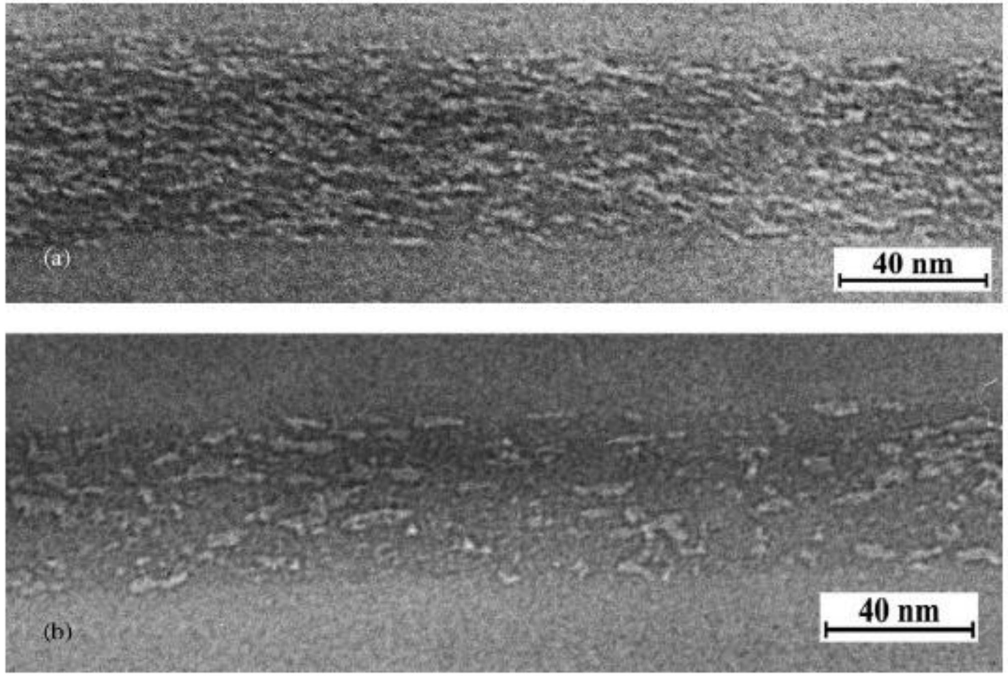


Figure1: TEM image of nanovoids in a direct bond after annealing at 400C (top) and 1000C (bottom). Picture from [7]

- HCB much thicker and more likely to have different mechanical (relevant for smooth polishing) and optical properties
- Direct bond not a « perfect » interface either

University of Glasgow

DZA Deutsches Zentrum für Astrophysik

Towards a composite mass

	Hydroxide Catalysis Bond	Direct bond
Resonant modes	Little effect	Little effect
Precise bonding	Bond has a settling time to adjust alignment	Bond grabs instantly and parts need to be pre-aligned !
Process compatibility	Oxide layer !	Annealing for strengthening !
Manufacturability of bonded parts	Done before – bond layer might have different polishing rate from bulk	Promising initial tests
Strength	Likely sufficient – 30MPa	Likely sufficient – maybe some margin on annealing
Mechanical loss	Need modelling !	Need modelling !
Absorption	Oxygen content !	Micro/macro voids !
Scattering	100 nm layer different RI !	40 nm layer, same RI !

Next steps

- Produce samples suitable for optical characterisation (absorption and scattering)
- Both reflected and transmitted beams
- Reach out to partners to scale up to larger samples, with expected new challenges regarding production of homogeneous bonds

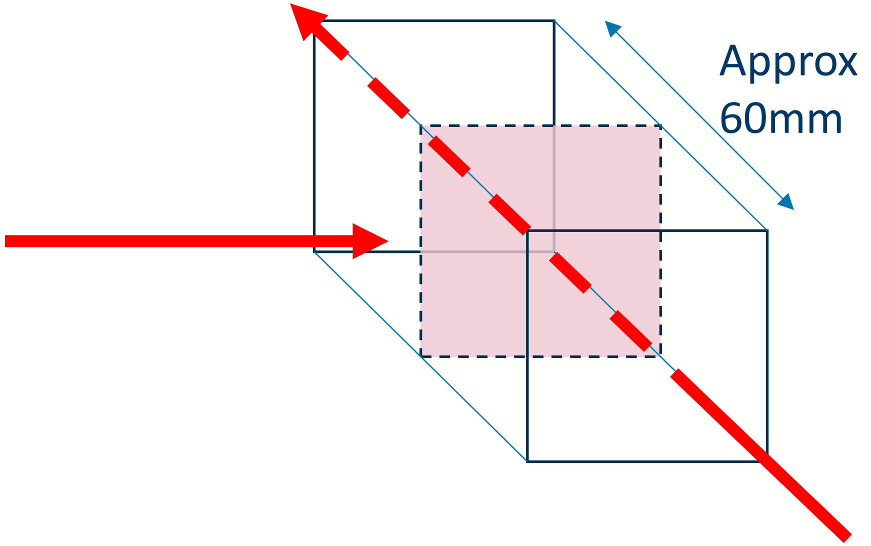


Figure1: Sketch of bonded sample geometry needed for optical characterisation, with all faces polished.

Conclusion

- We are looking at both Hydroxide Catalysis and Direct bonds to build a composite test mass
- Bond strength seems to be sufficient, both for processing and static load
- Need to adapt the processes to ensure feasibility and preservation of bulk properties
- Need to complete loss measurements and optical characterisation – Liaising with industrial partners at DZA for procurement and preparation of suitable samples

THANK YOU FOR YOUR ATTENTION

References

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