Perspectives on silicon-on-diamond devices

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CARAT 1st Workshop, **GSI**, 14 December 2009

OUTLINE

2007

A new method of diamond silicon-bonding (briefly described)

Material characterization: recent results

As of december 2009

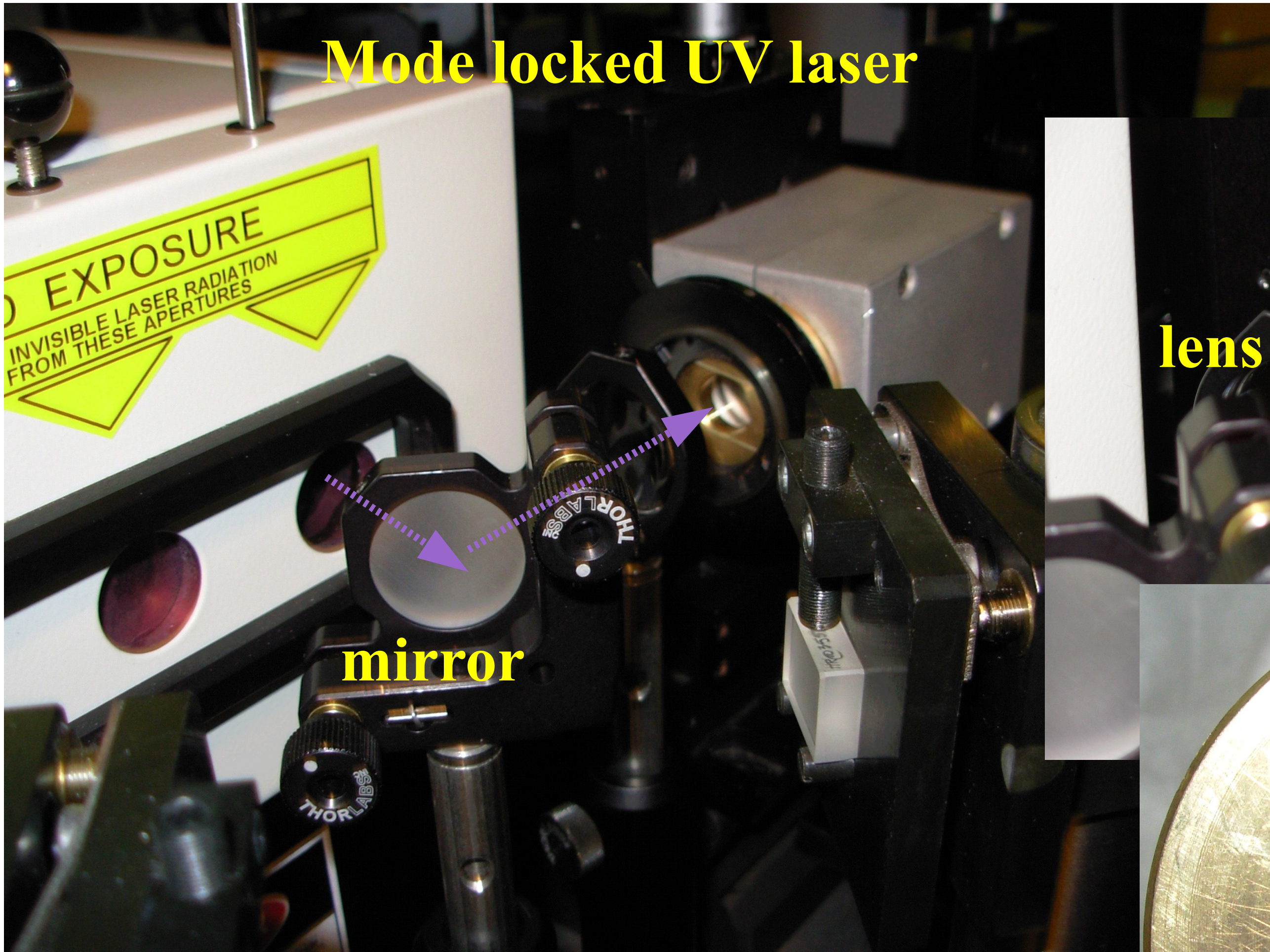
Theoretical modeling: recent results

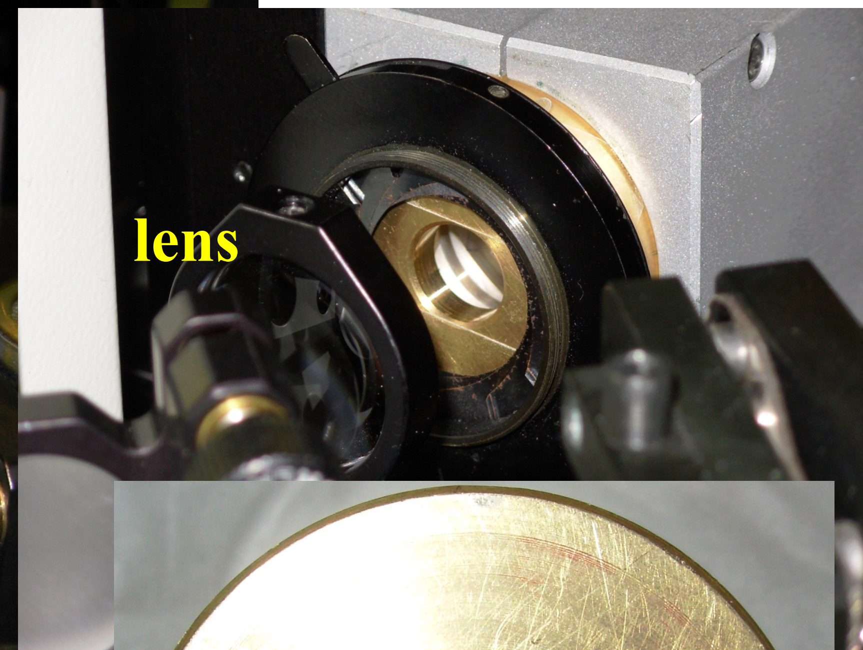
Silicon-on Diamond monolithic detectors

Silicon on diamond biological interface

2012?

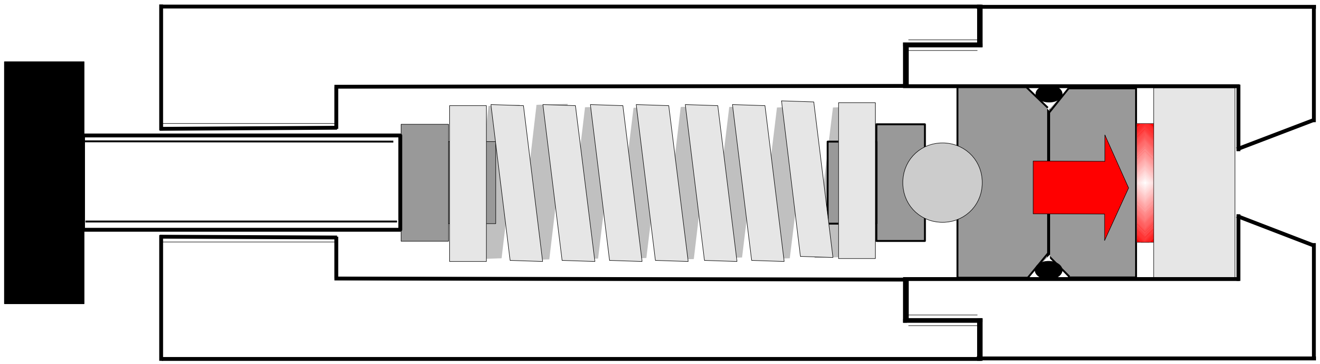
Laser enhanced silicon on diamond bonding

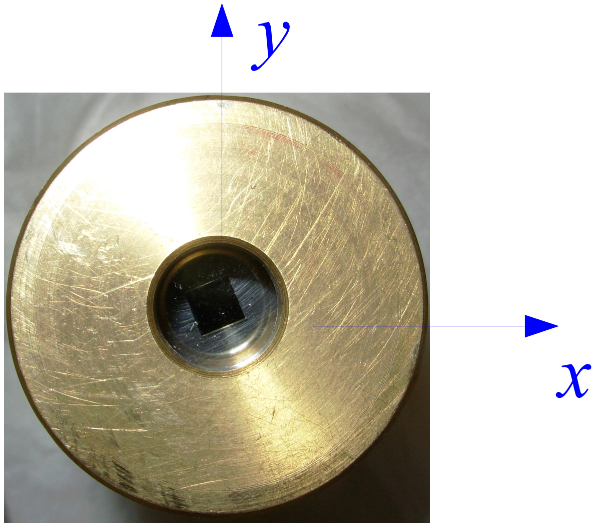




Si and diamond plates seen through the viewport of the sample holder

Sample holder (on xyz linear stage)



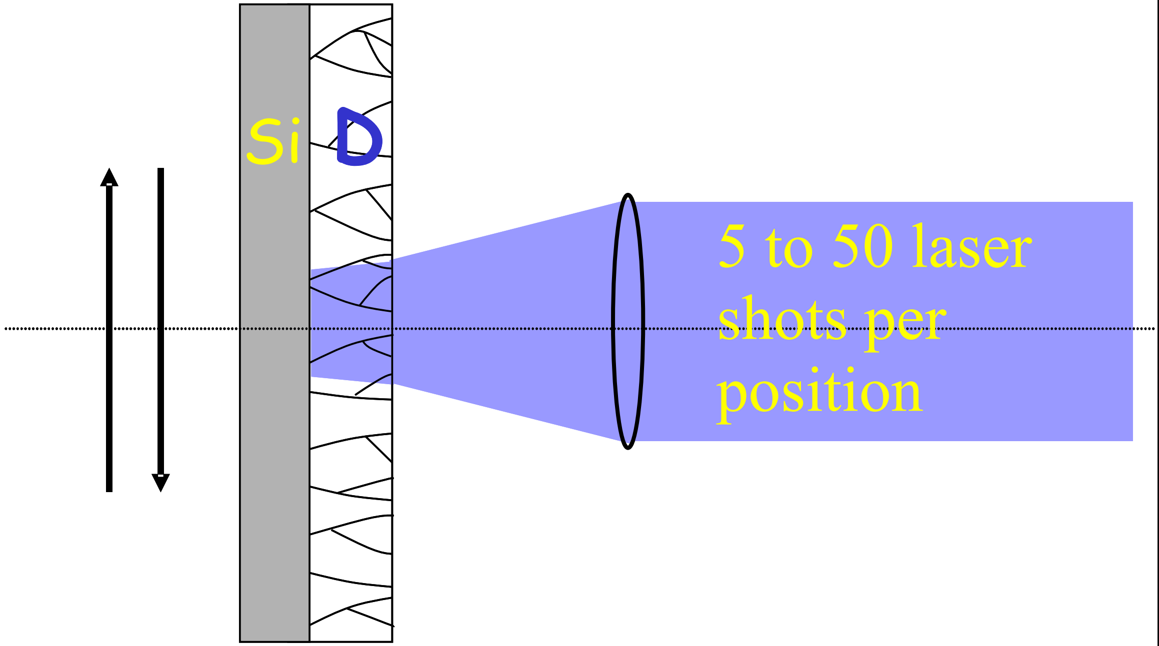


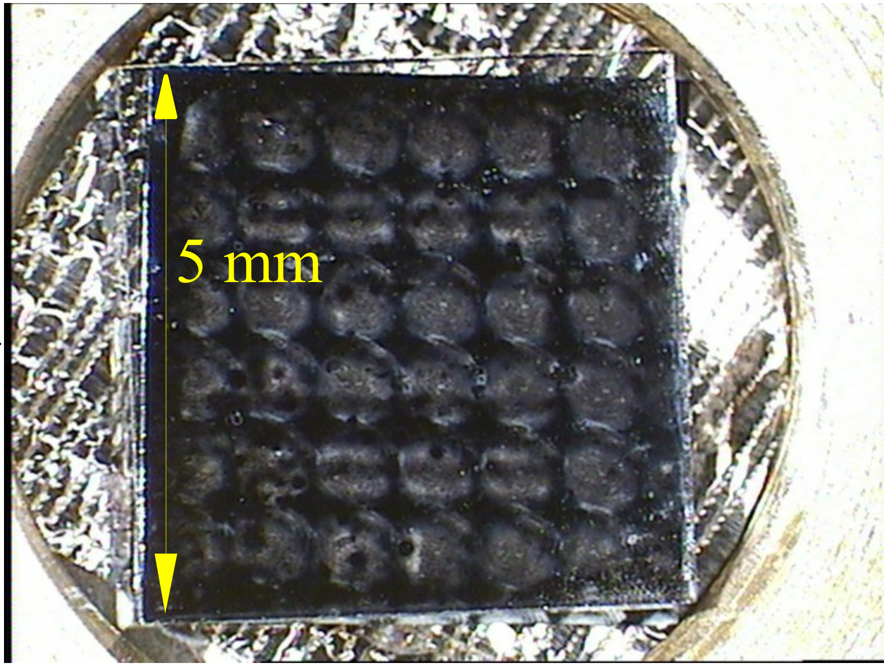
Silicon and diamond plates, under 80 Mpa uniaxial stress,

irradiated by 20 ps-7ns 355 nm laser pulses, at 1 -10 J/cm^2

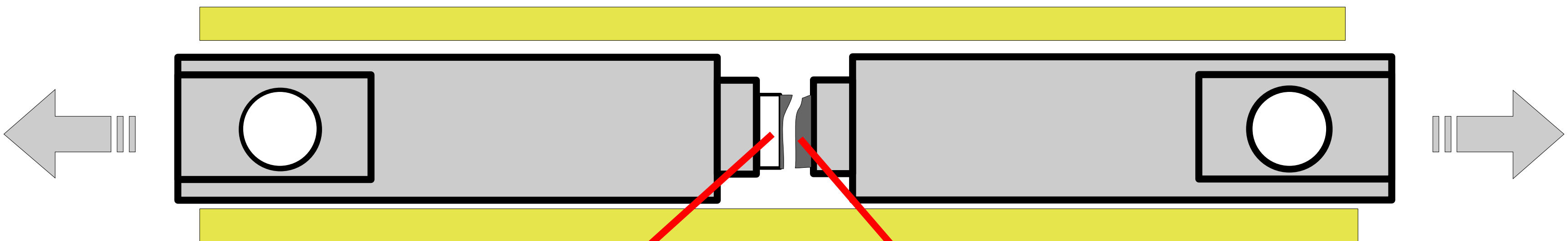
stopped within 10 nm of Si,

causing melting of Si and diamond and SiC formation

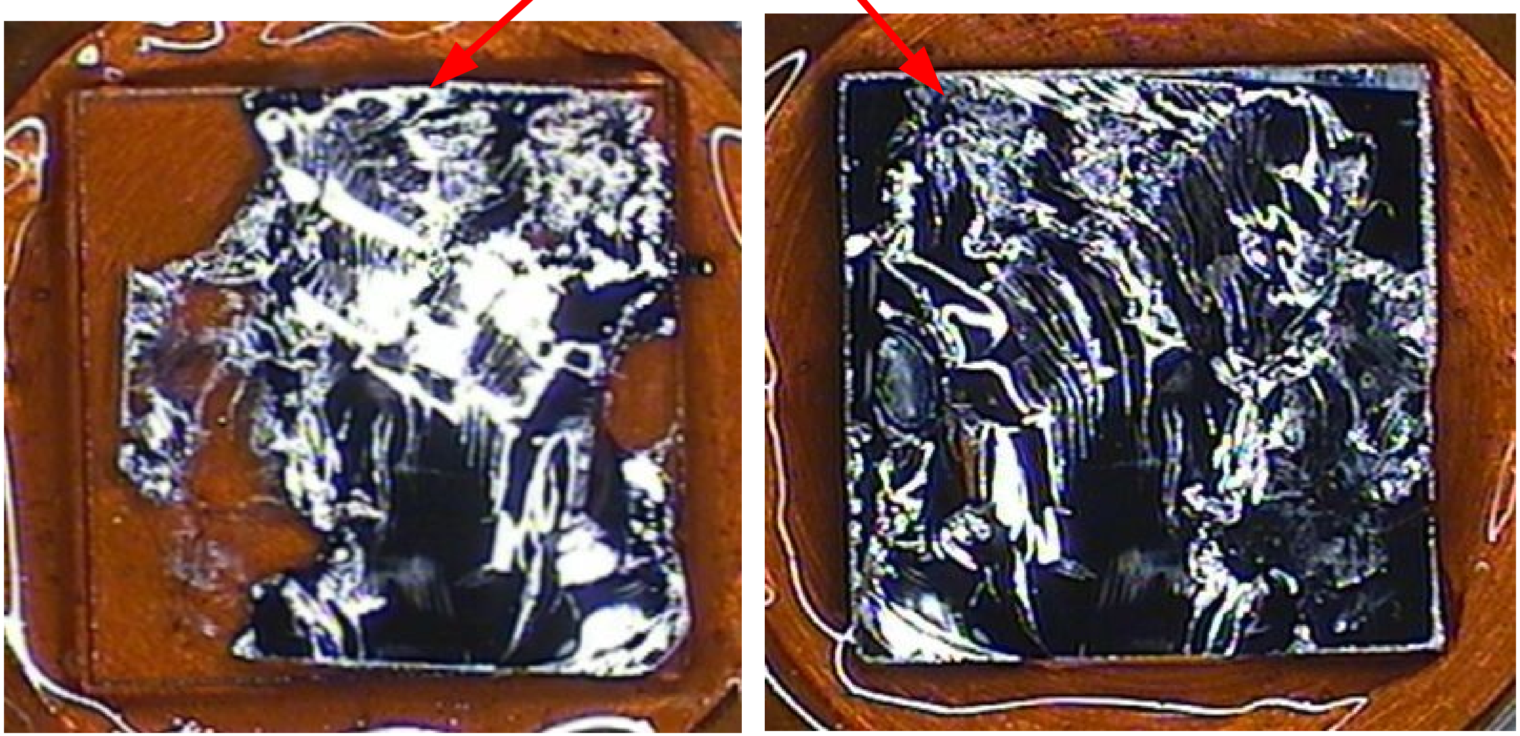




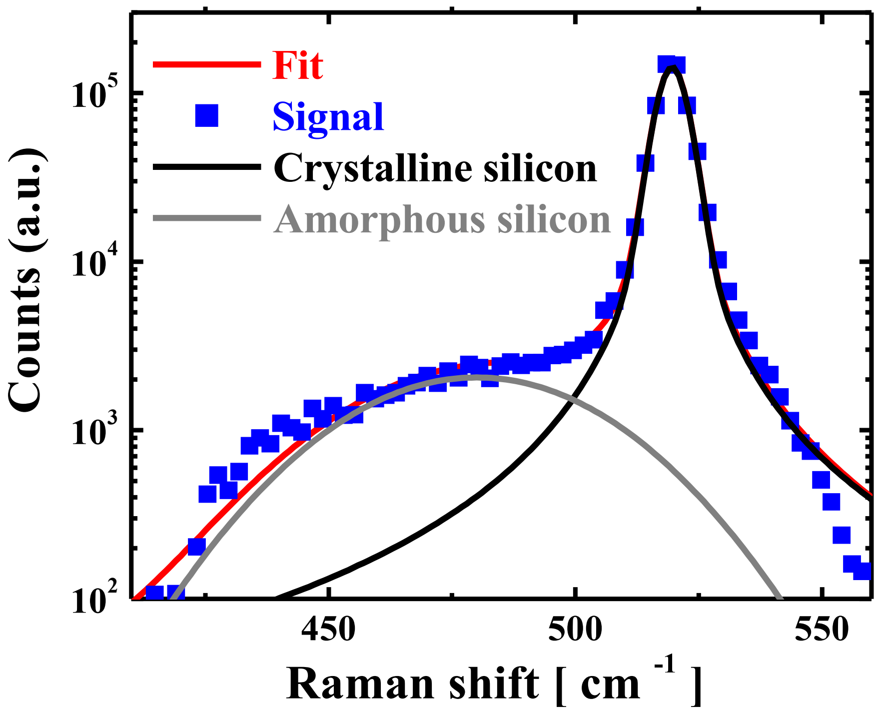
SoD Mechanical strength higher than 12 MPa

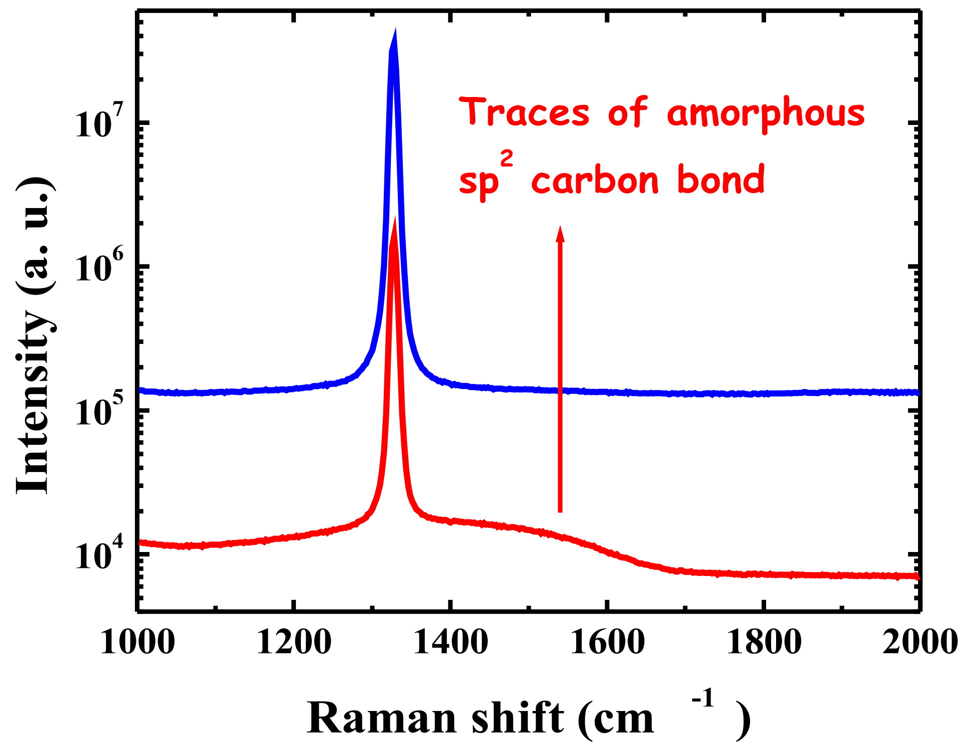


Si bulk cracked (mainly) away from the interface



Optical Spectroscopy (Raman with Kr red lines)





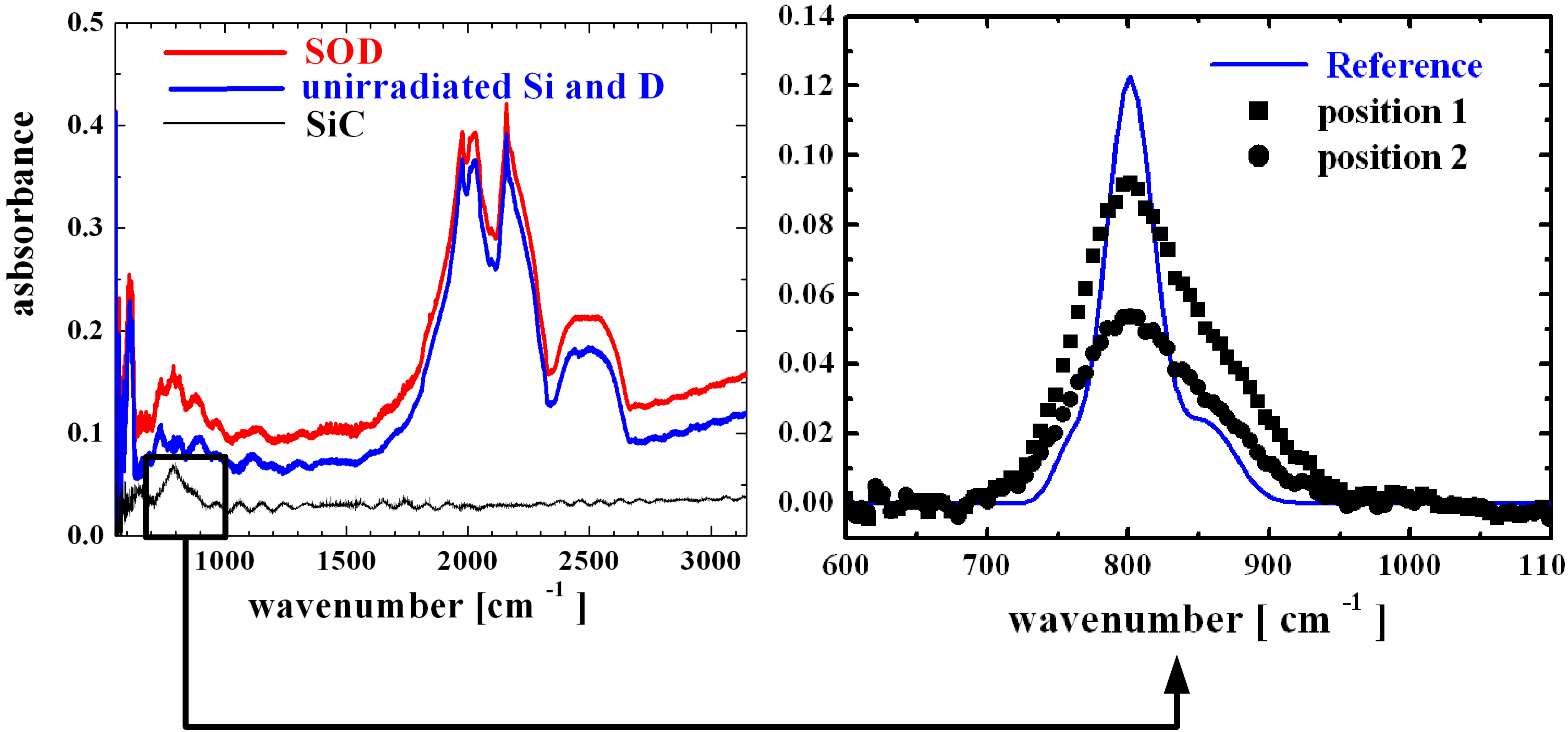
Average a-Si thickness 85 nm

Dependence on energy per pulse to be assessed

a-C at the limit of our detection capability...

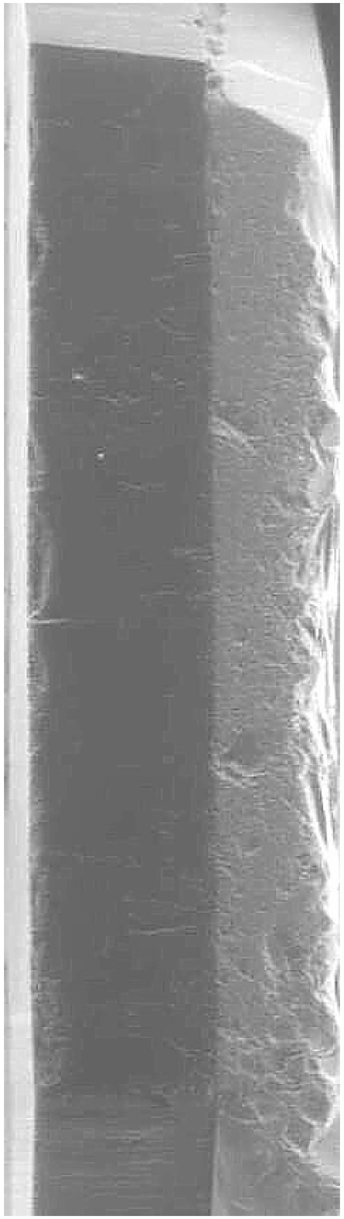
Optical Spectroscopy (FTIR)

Reference: M. Friedrich, S. Morley, B. Mainz, S. Deutschmann, D. R. T. Zahn and V. Offermann, "Detection of Ultrathin Sic Layers by Infrared Spectroscopy," Phys. Stat. Sol. (a)145, 369 (1994).

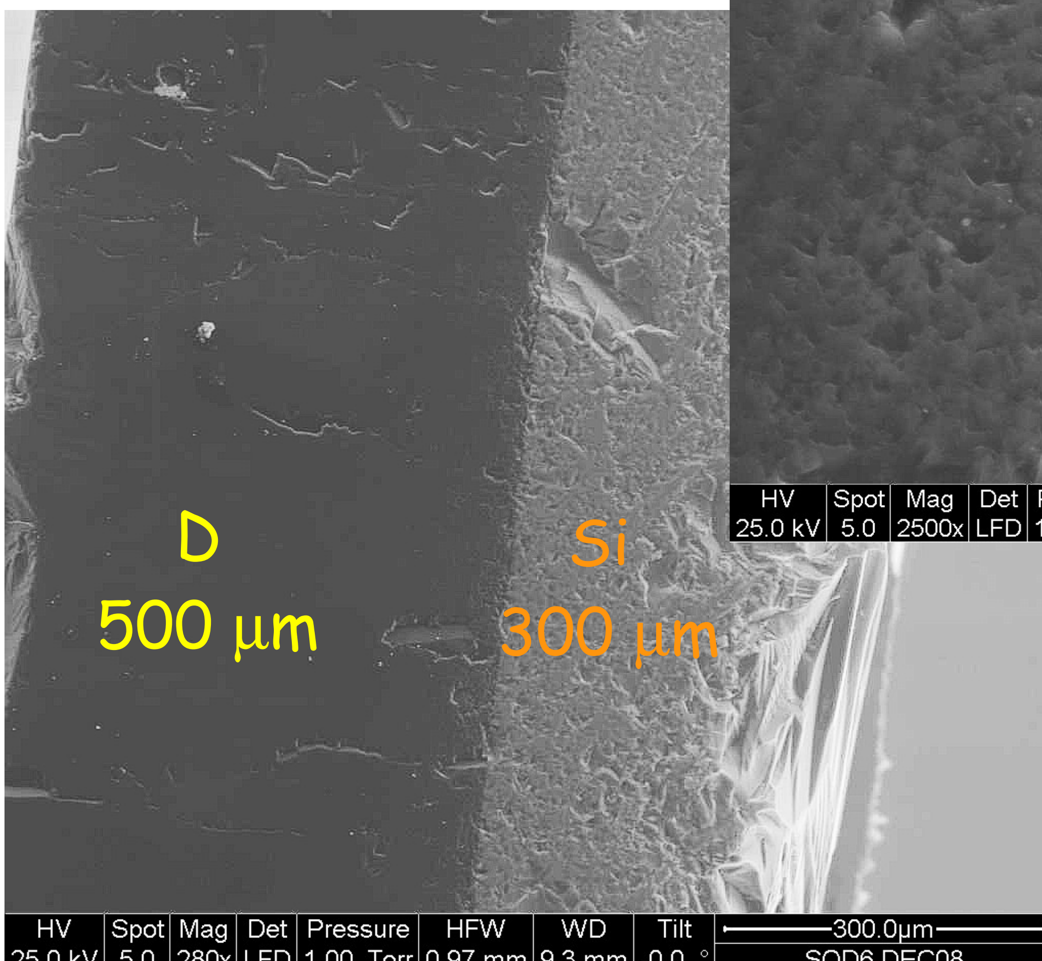


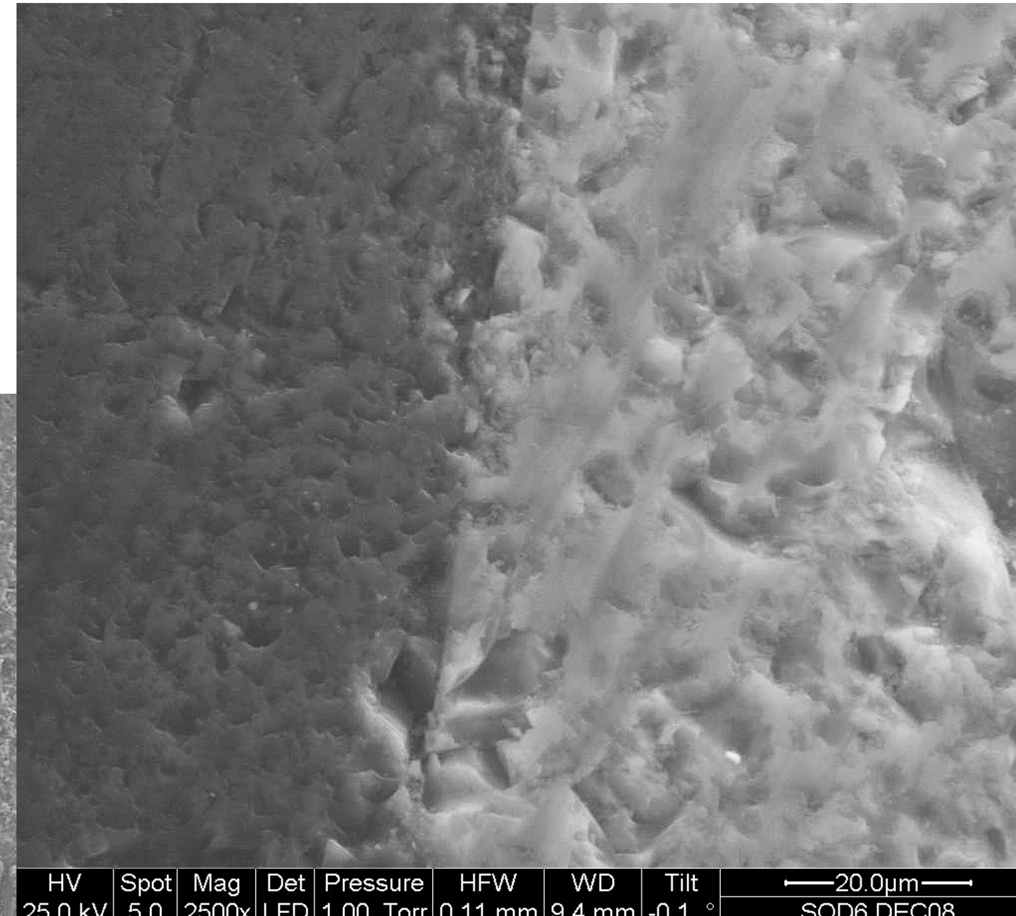
SIC layer from about 50 nm for the highest number of laser shots per position (50), to below 3 nm with 10 laser shots

Electron Microscopy (SEM)



SOD
cross-section

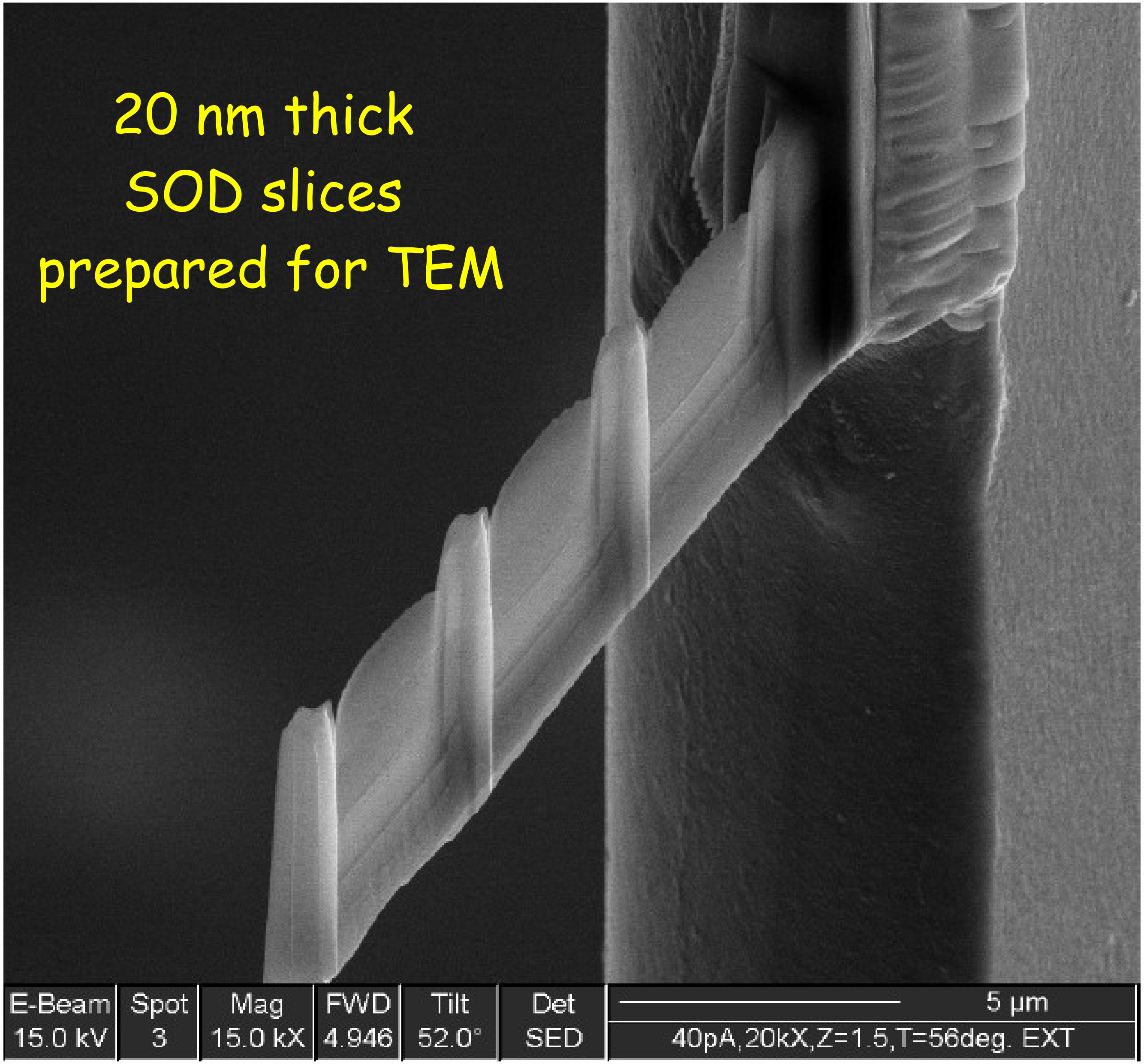




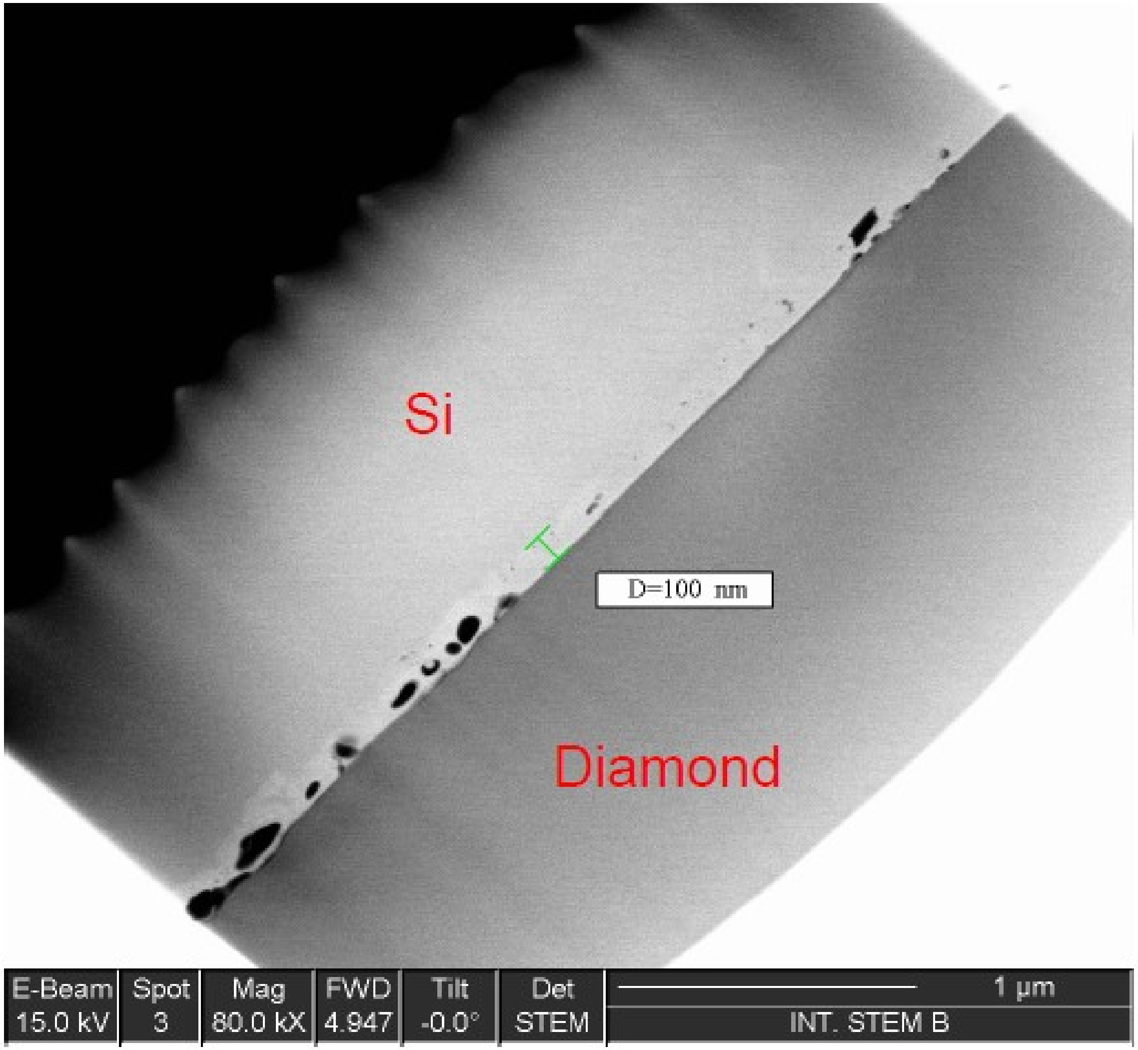
Uniformity on
a μm scale

Electron Microscopy (FIB)

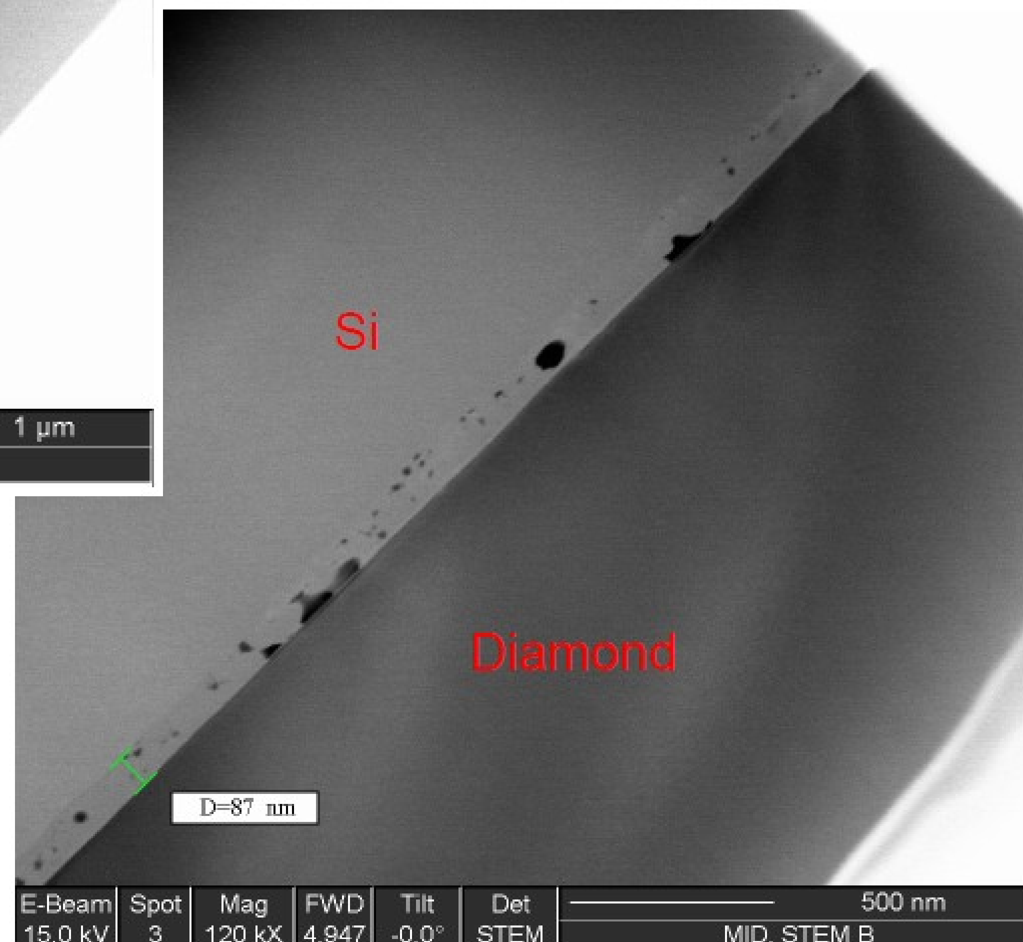
A. Scorzoni (University of Perugia) & S. Frabboni (University of Modena)



STEM analysis
(A. Scorzoni & S. Frabboni)



From 100 to200 nm thick interface



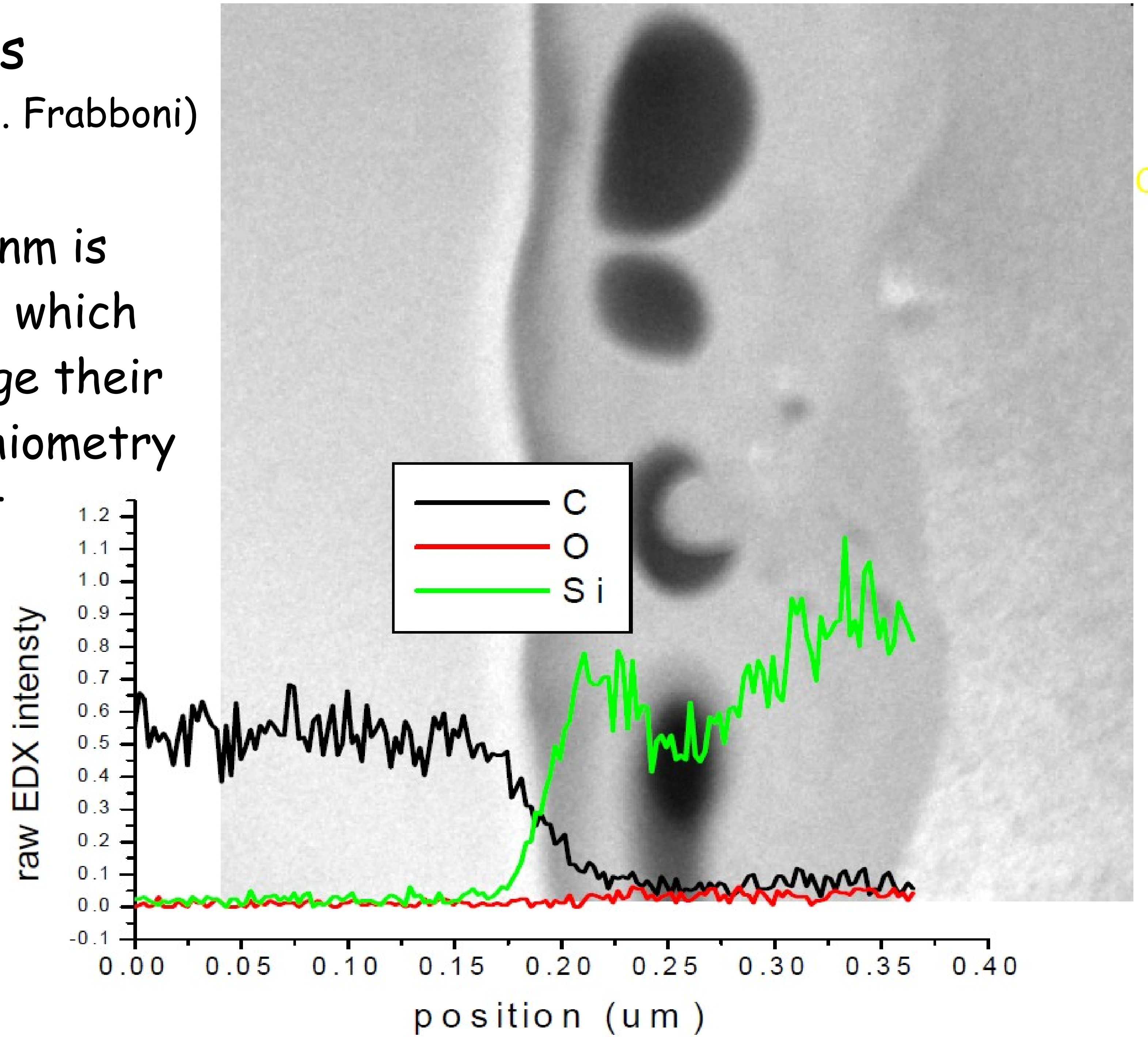
Spectroscopy evaluation of interface thickness confirmed

Presence of voids

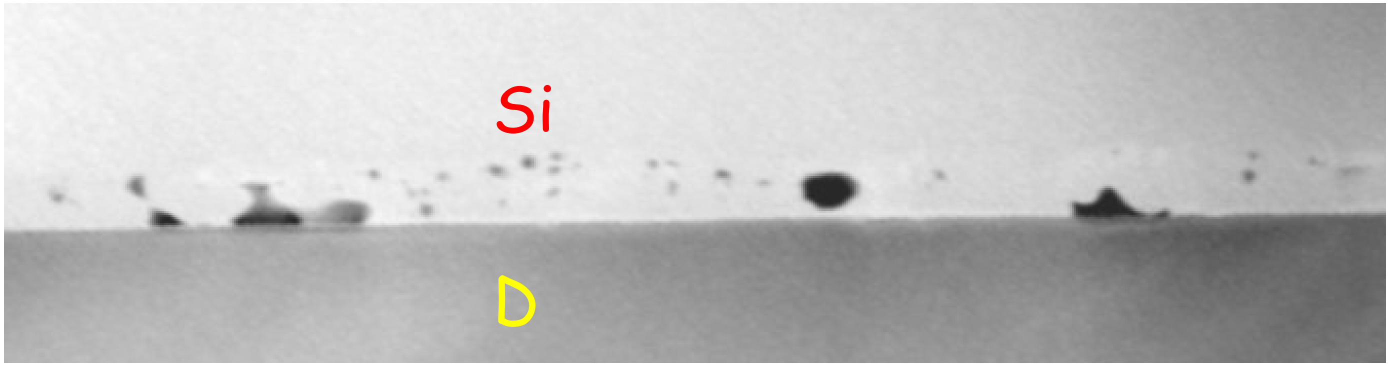
EDX analysis

(A. Scorzoni & S. Frabboni)

A layer of 50 nm is observed over which Si and D change their relative stoichiometry in agreement with FTIR results

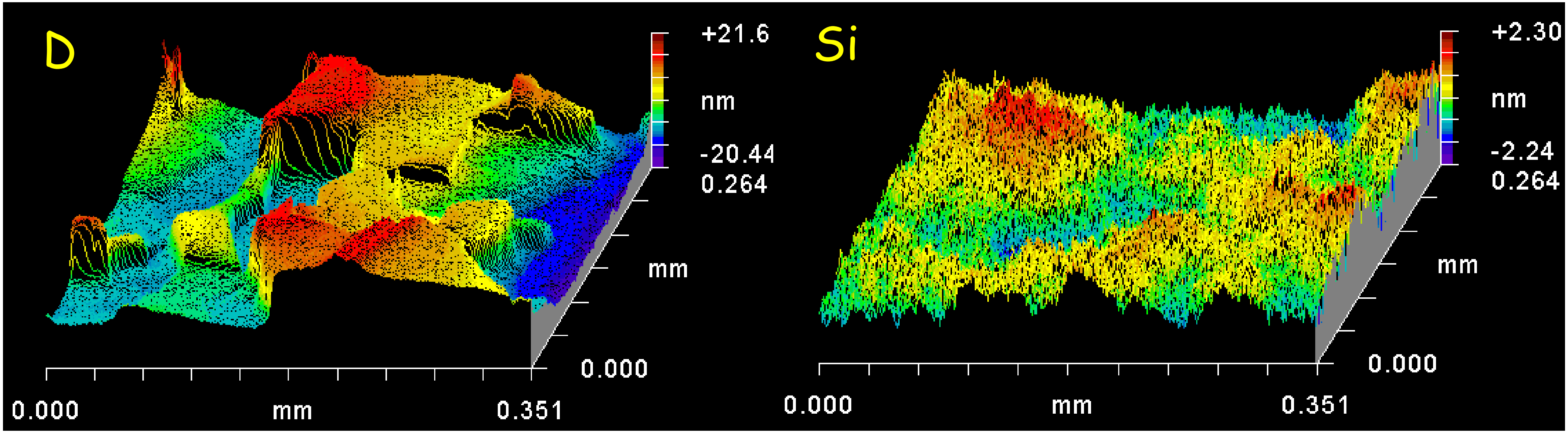


Origin of the voids at the Si-D interface?



Surface roughness of diamond (higher than that of Si)?

Higher density of the formed SiC phase with respect to D and Si?

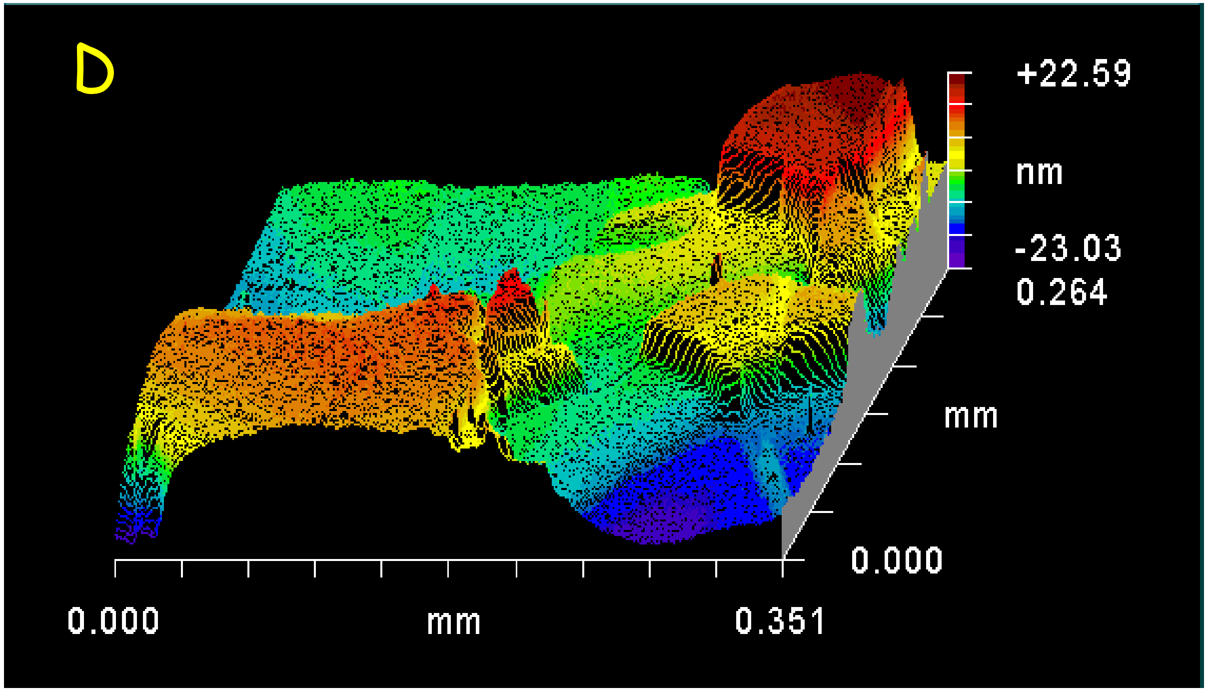


Under our initial pressure condition (800 atm) a small fraction of the Si surface does not contact the D surface

As the Si melts it covers a distance of some nanometers in a time interval of nanoseconds

But our pulse width is in most cases τ = 20 ps
(why did we choose that τ?)

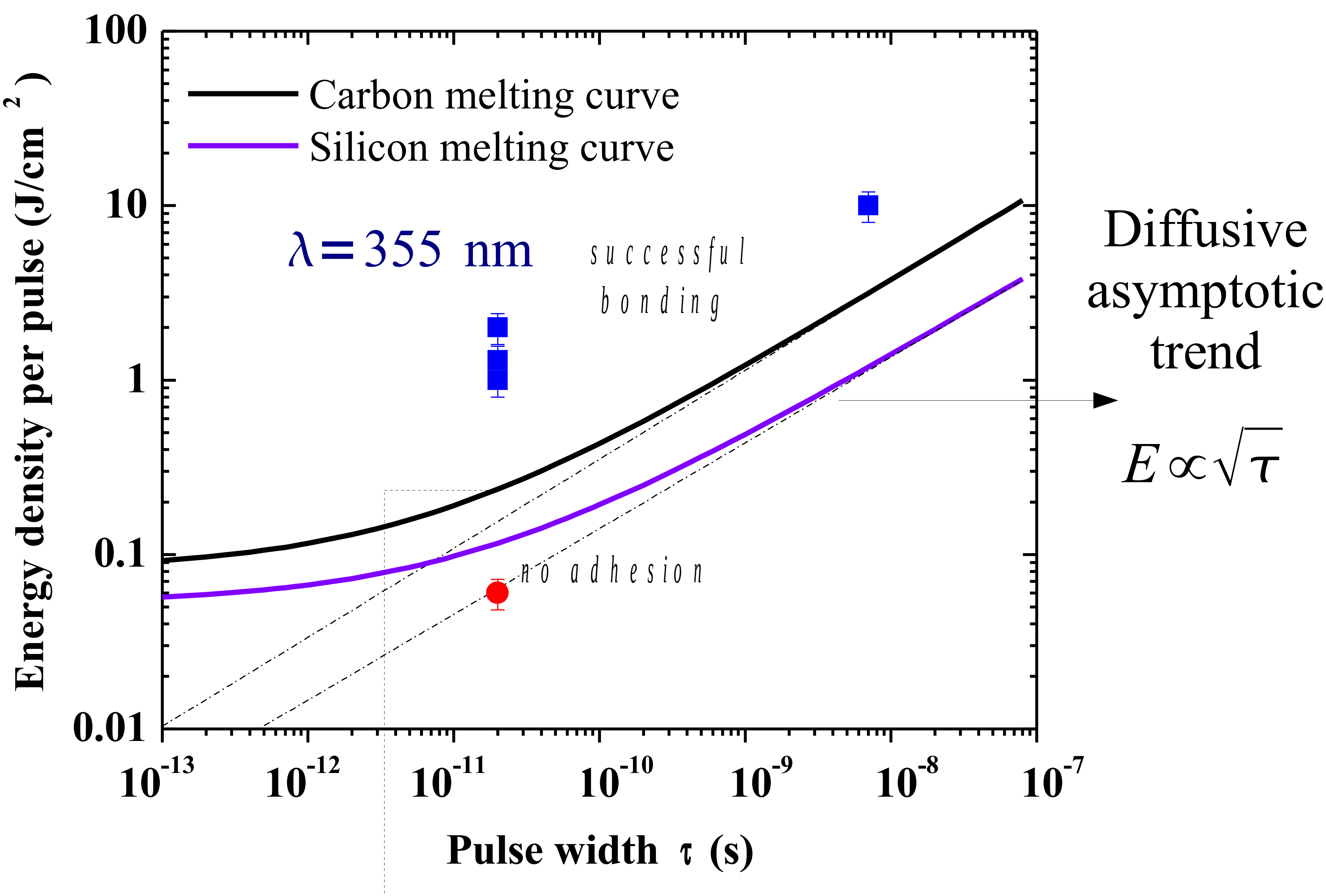
Regions of Si which are not initially in contact will never reach diamond by irradiation



How much can we improve this with a higher polishing?

We tried to find answers in theoretical modeling

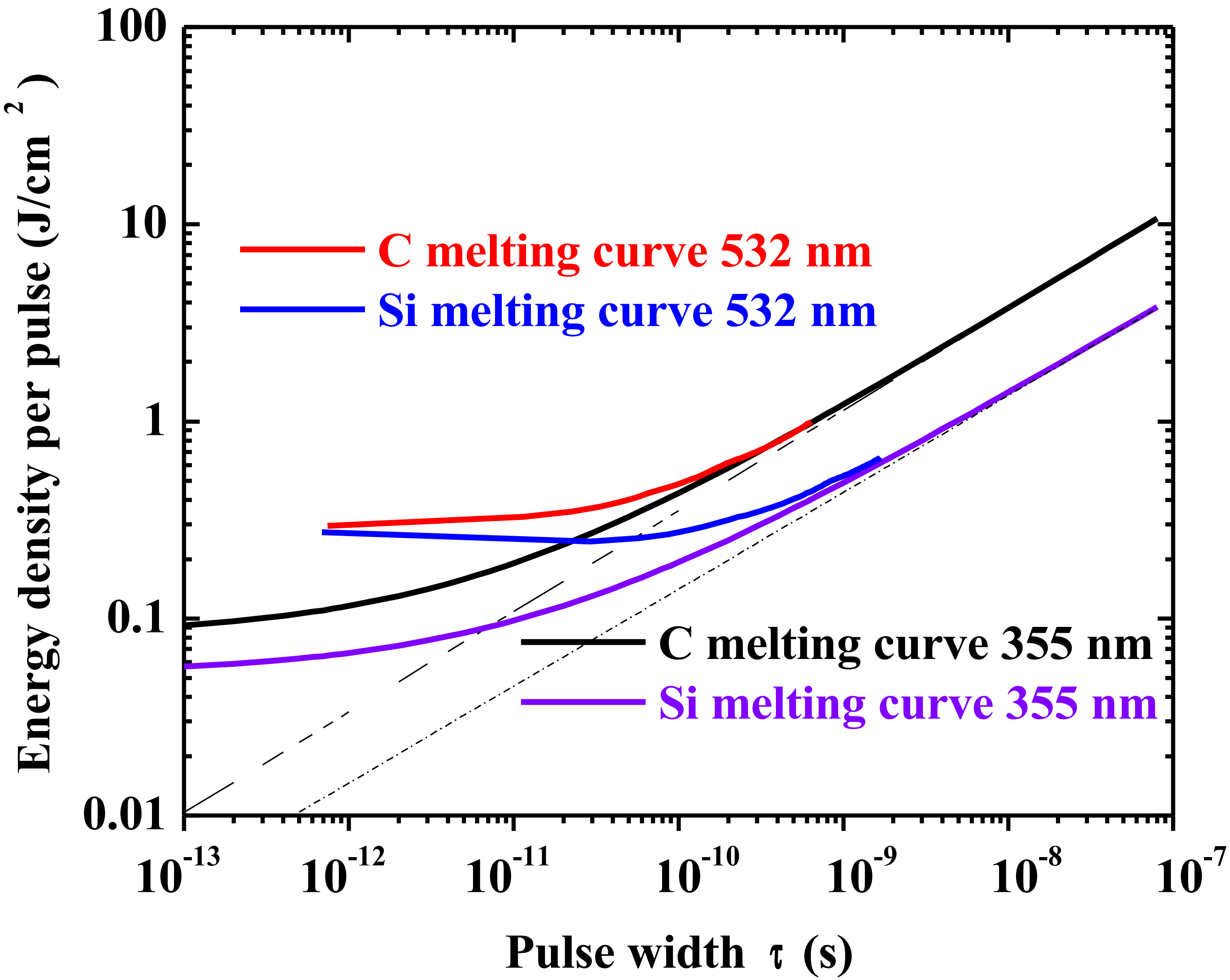
input	model	output
Wavelength, pulse width	Reflection, e-h pair creation, diffusion and recombination, energy transfer to lattice	**Energy threshold** for D (Si) melting, **thickness** of the interface
Surface profile, applied pressure	Calculation of the deformation of the Si surface, onto a perfectly rigid D material	**Fraction of surface area in contact** before the bonding process



Smaller amorphous interface at an energy closer to the threshold (0.25 J/cm^2 for τ =20 ps)

Note: an higher τ requires an higher threshold energy

Energy threshold



Longer wavelenths require higher energies

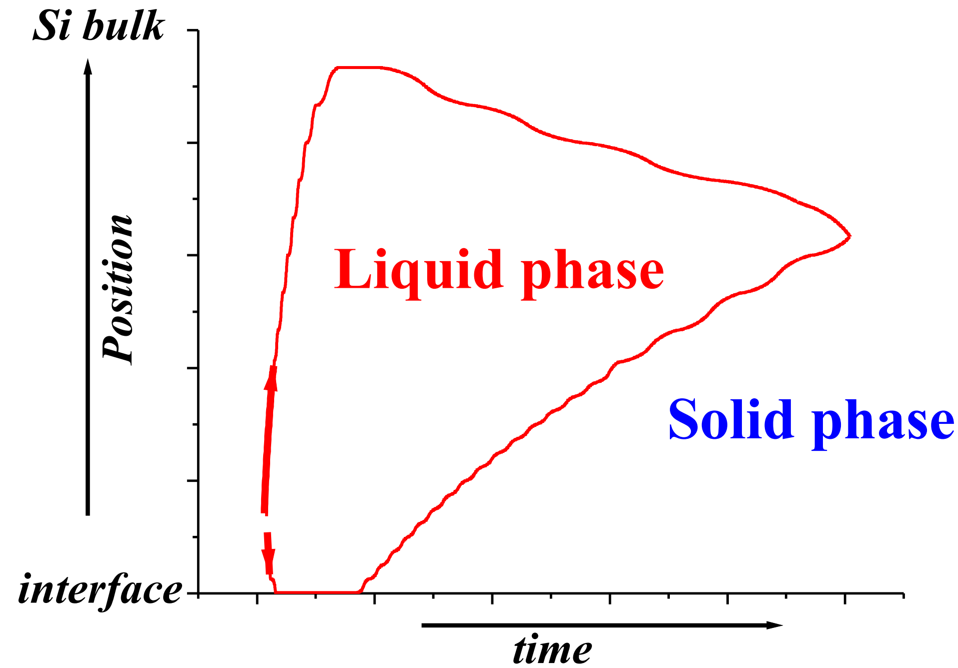
because of the higher penetration depth of the incoming radiation

Evolution of the melted Si phase

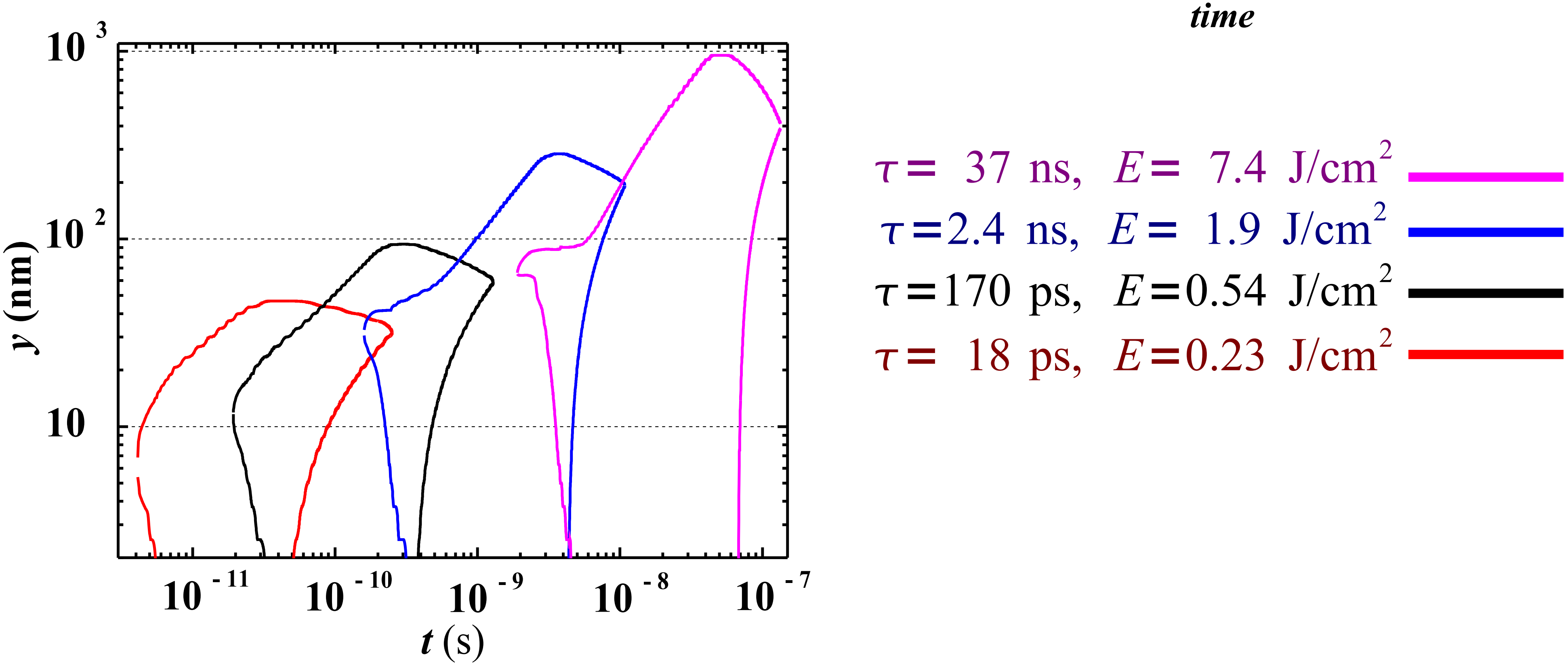
Minimum extent of the modified interface region:

50 nm at a 20 ps pulse width

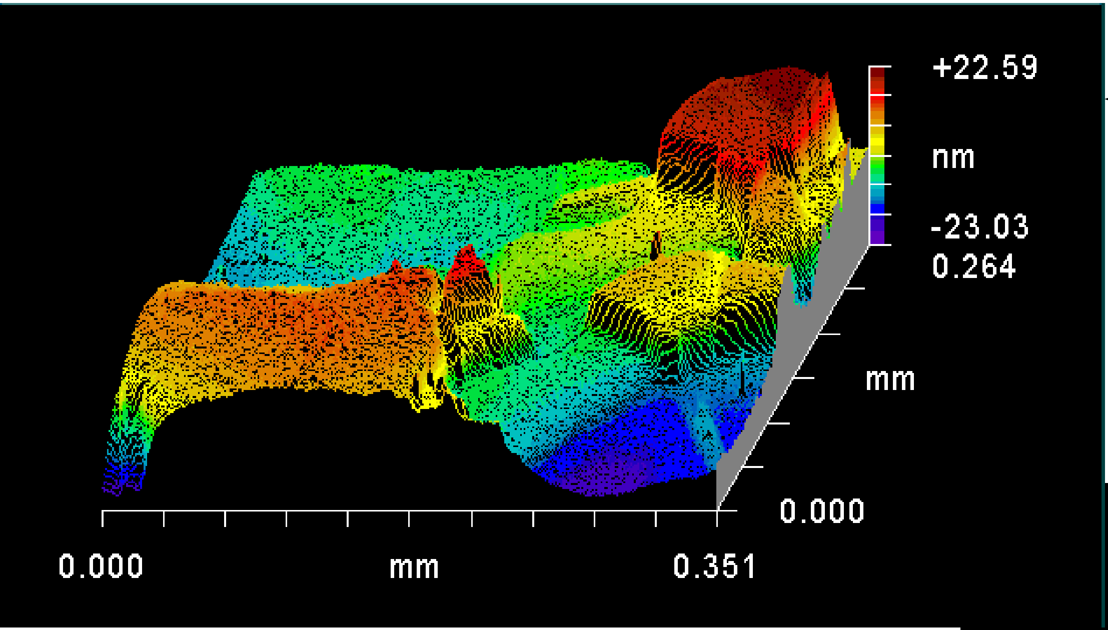
(energy threshold: E= 0.25 J/cm^2)



Probably decreasing with a lower pulse width

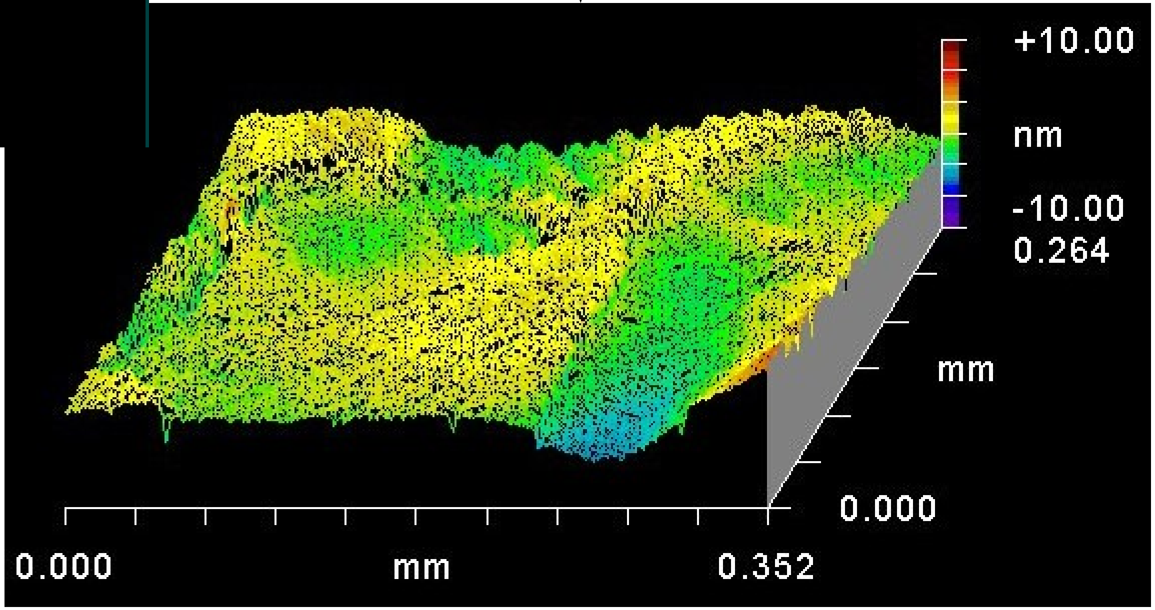


Pre-adhesion of the surfaces



Diamond sample from an old batch

Diamond sample from a NEW batch

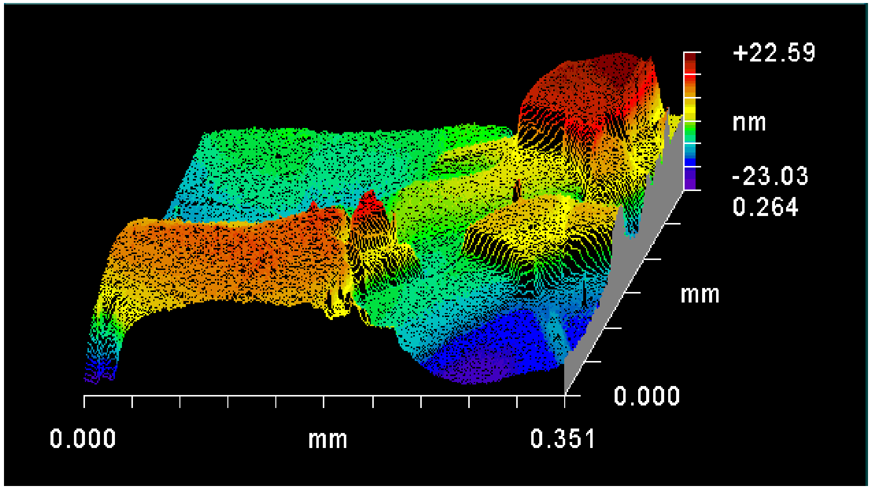


Pressure required for perfect contact:

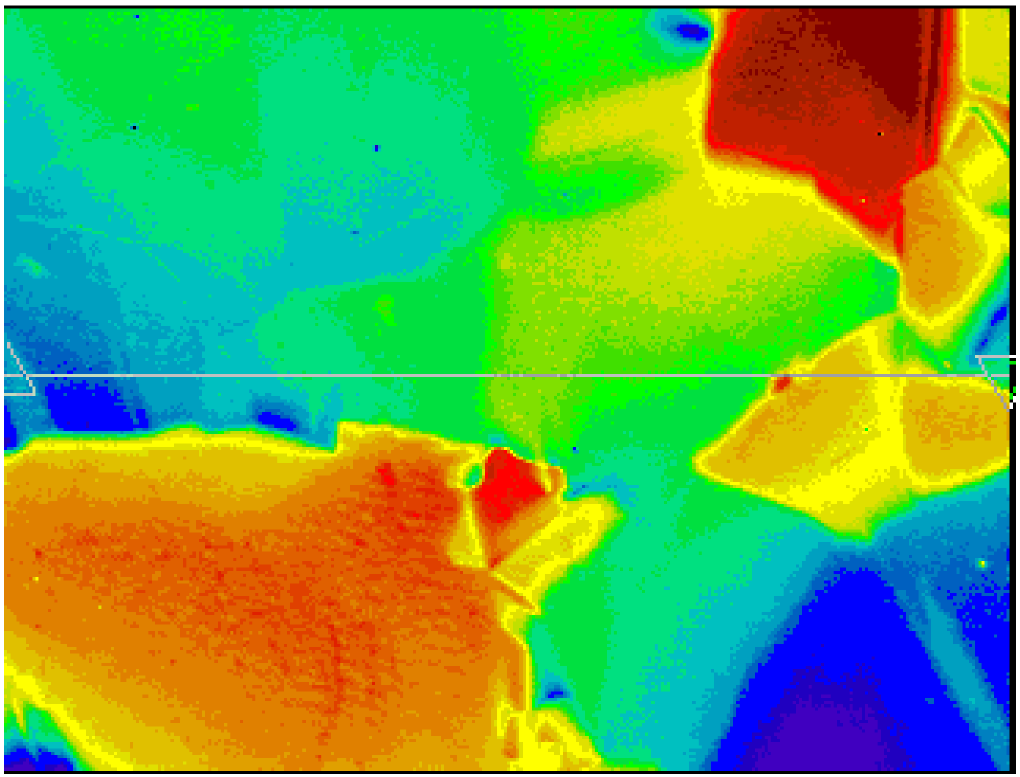
$$P_0 \times F$$

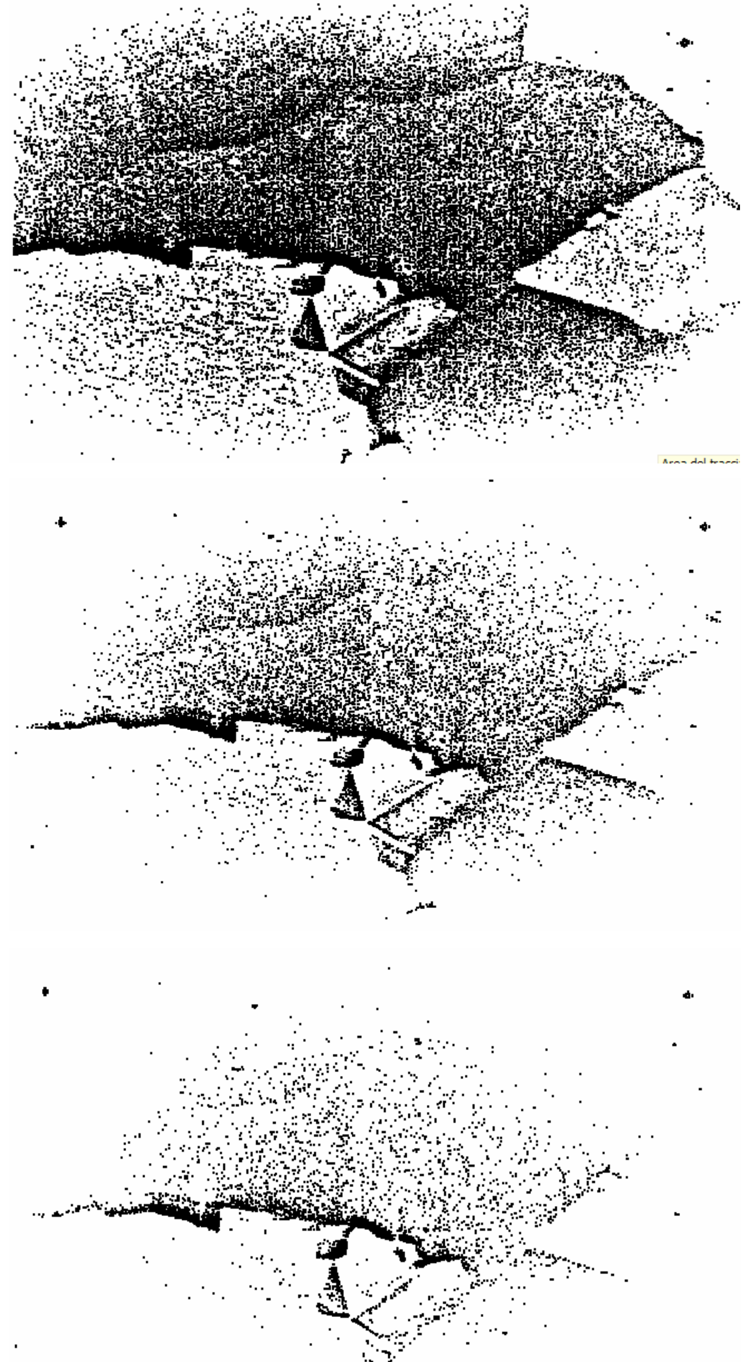
$$\sim 90 \text{ GPa} \times (0.02 - 0.1)$$

F : factor calculated via the measurement of the whole surface profile



Some numbers:





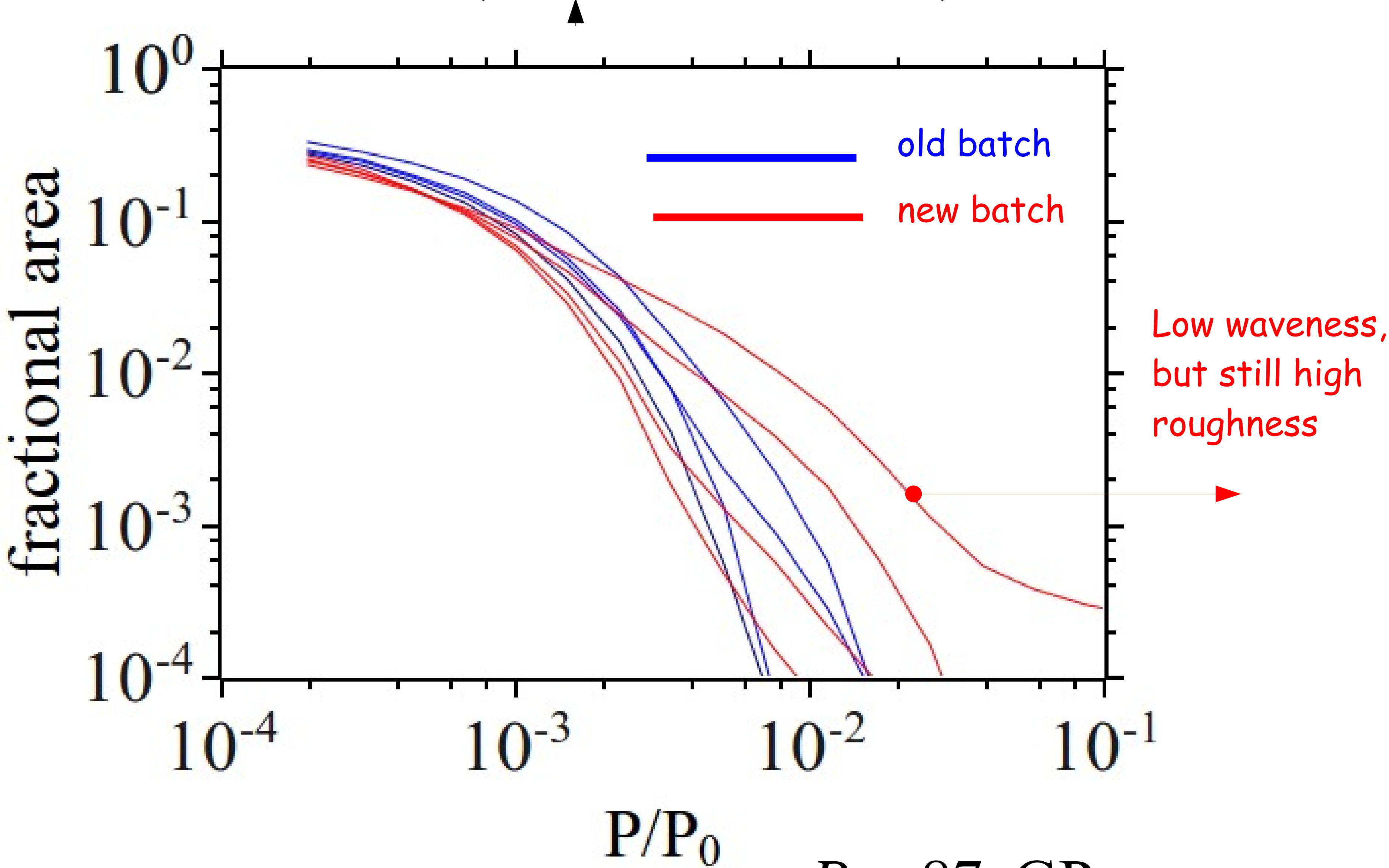
80 MPa, 11 %

160 MPa, 3.7 %

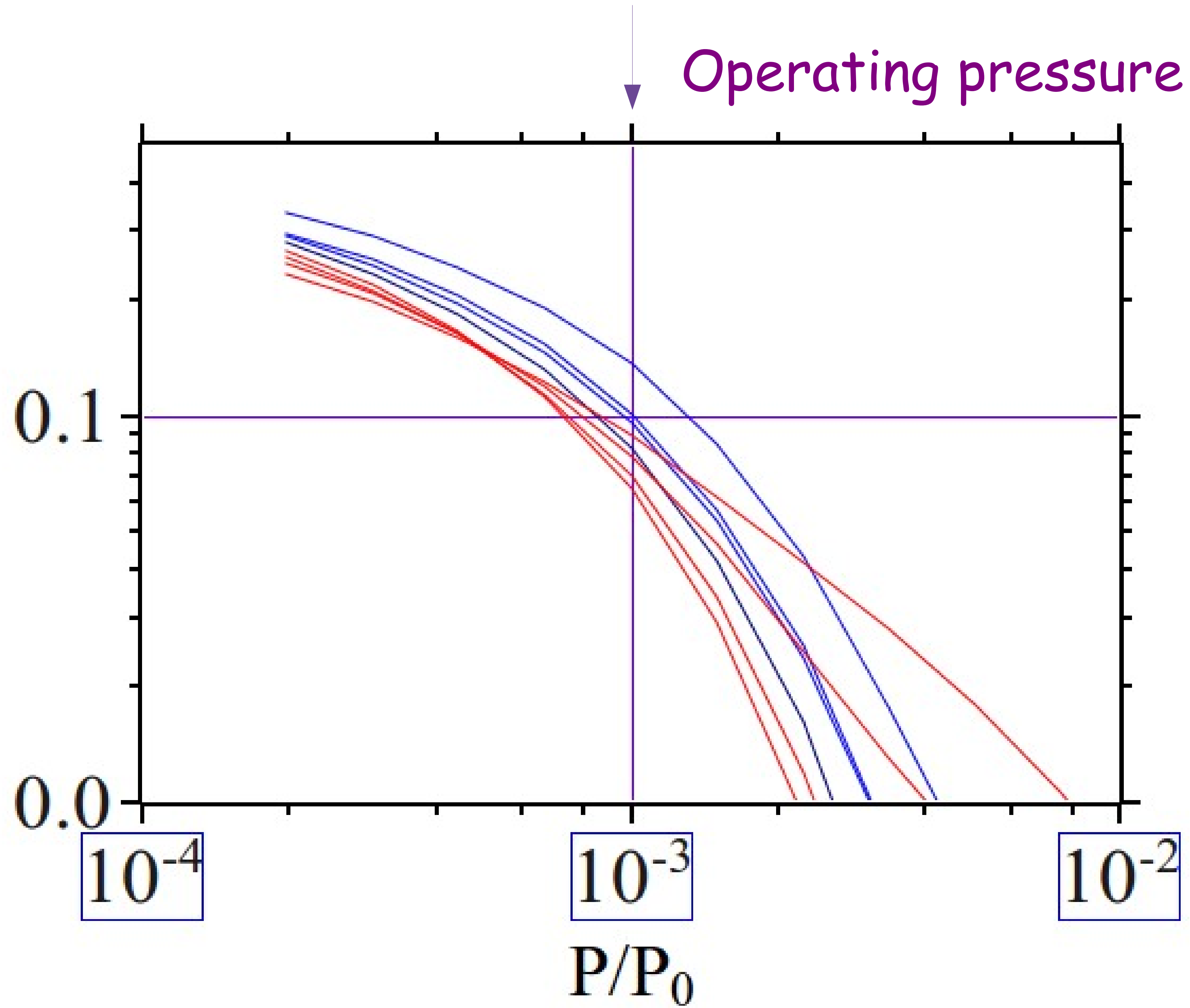
240 MPa, 1.4 %

Diagrams of uncontacted surface area (for this sample profile) →

Fraction of uncontacted surface

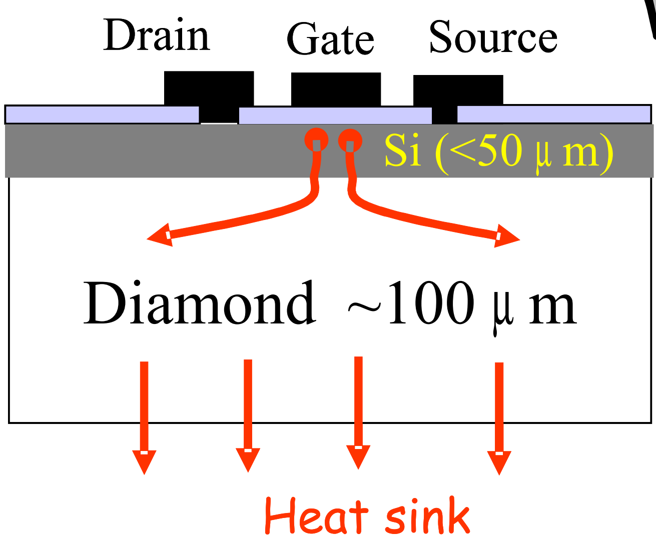


$P_0 = 87$ GPa



Latest batch delivered last week: Ra < 2 nm on a mm scale (to be evaluated)

Why did we do all this?



Concept of SOD as SOI

Katerina Raleva, Dragica Vasileska, and Stephen M. Goodnick, "Is SOD Technology the Solution to Heating Problems in SOI Devices?" IEEE ELECTRON DEVICE LETTERS, VOL. 29, NO. 6, JUNE 2008

Recent research

Silicon-On-Diamond layer integration by wafer bonding technology M. Rabarot, J. Widiez, S. Saad, J-P. Mazellier, C. Lecouvey, J-C. Roussin, J. Dechamp, P. Bergonzo, F.Andrieu, O. Faynot, S. Deleonibus, L.Clavelier, Diamond 2009, Athens, Greece

"Pure" SOD for electronic devices /GaN (epi layer) on SOD for high power devices

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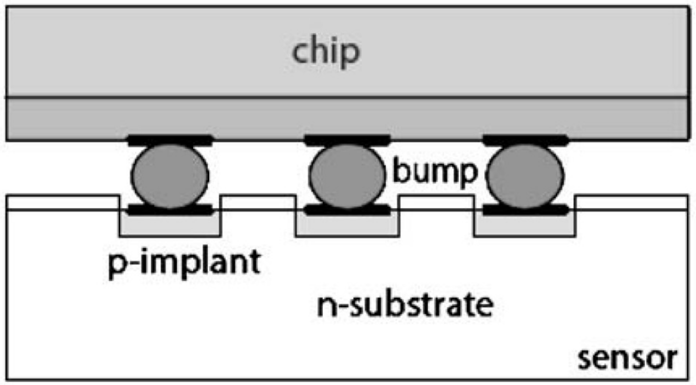
GROUP4LABS
AN EXTREME MATERIALS COMPANY

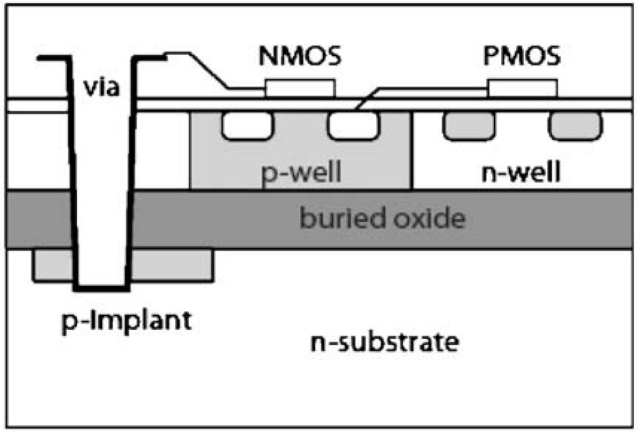
http://group4labs.com/

GaN on diamond is on the market

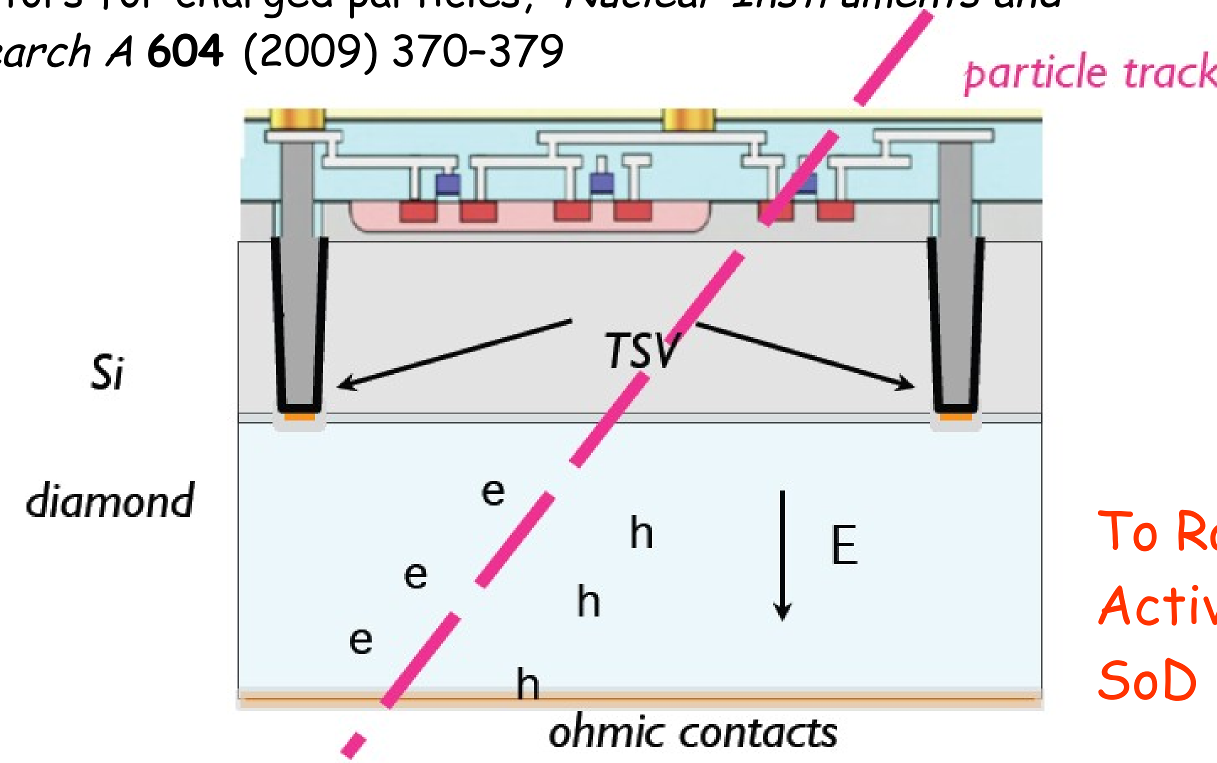
Perspective1: SoD detectors

From hybrid sensors to MAPS



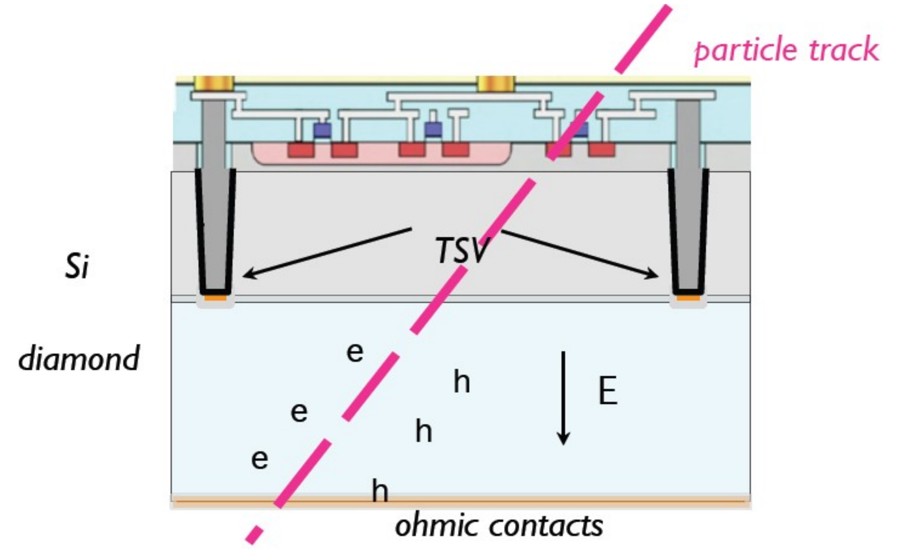


N. Wermes, “Pixel detectors for charged particles,” *Nuclear Instruments and Methods in Physics Research A* **604** (2009) 370–379



To Radiation Active Pixel SoD Sensors

Perspective 1.
SoD monolithic detectors

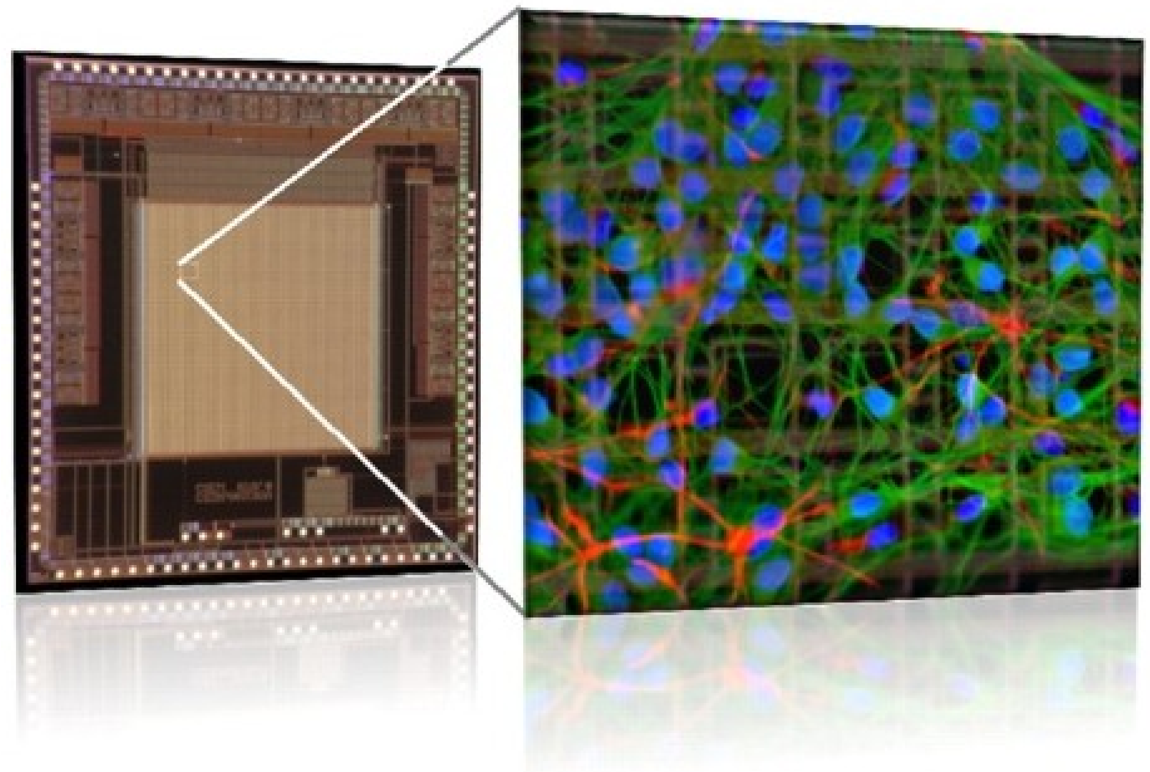


Research items

- Front-end and readout Si IC (die)
- Die thinning and polishing (back)
- Die bonding onto diamond
- Laser Machining of Through Silicon Vias
- Ohmic contacs fabrication on diamond

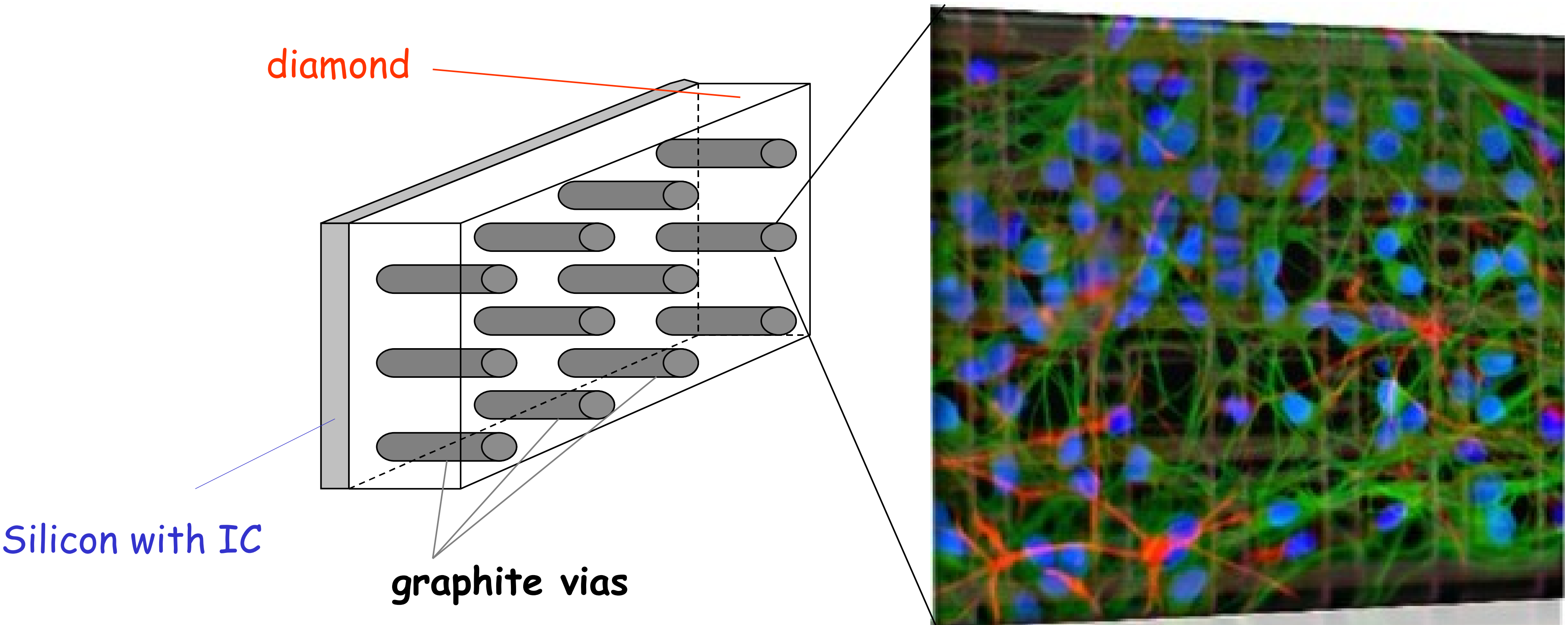
MicroElectrode Arrays(MEA)

MEA on APS (CMOS) structured 64 x 64 pixels (2.5 mm x 2.5 mm) with 40 µm pitch Each pixel hosts microelectrode (20 µm x 20 µm) and amplification circuitry. The chip (5 mm x5 mm) integrates the read-out with a 8 kHz. frame-rate



L. Berdondini et al., *Active pixel sensor array for high spatio-temporal resolution electrophysiological recordings from single cell to large scale neuronal networks, LabChip*, 2009, 9, 2644

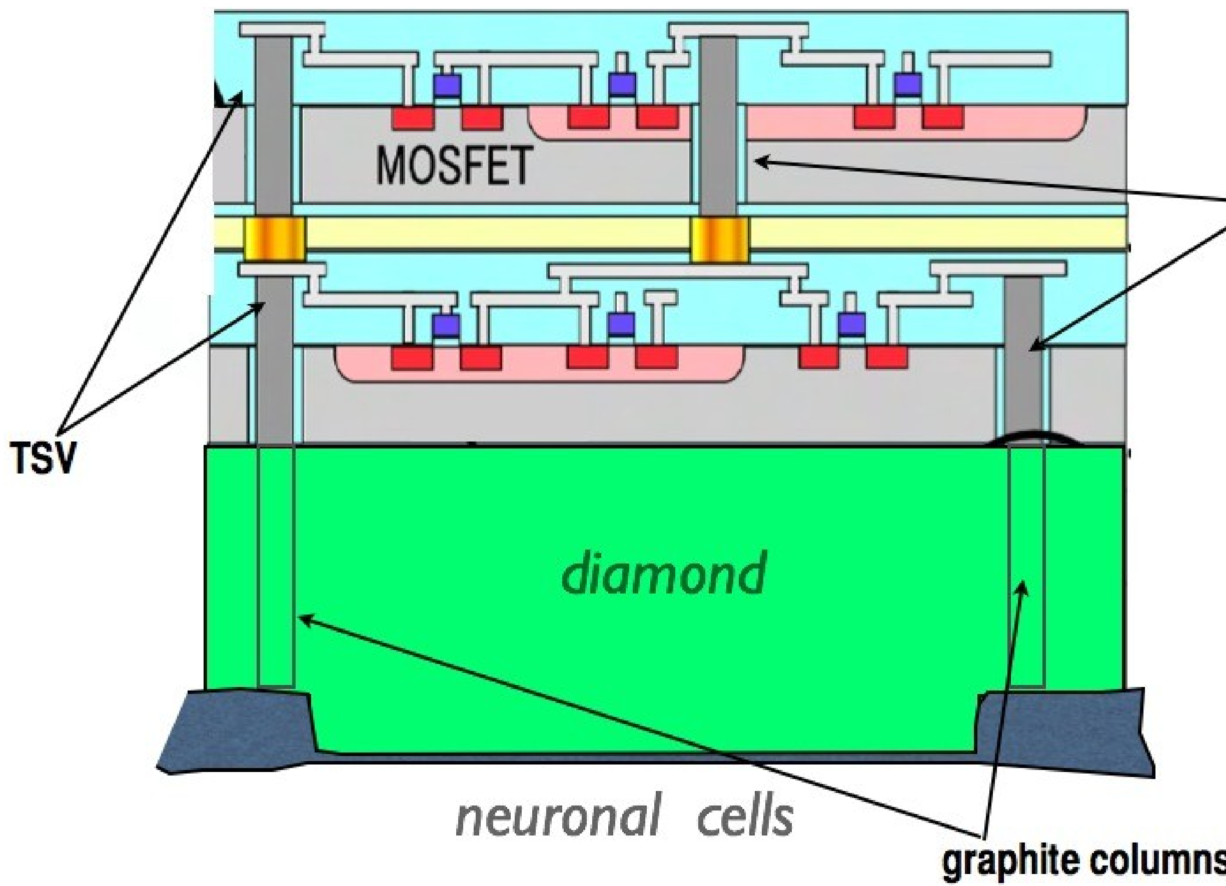
Perspective 2: Exploit diamond bio-compatibility to develop integrated interfaces to biological neural networks



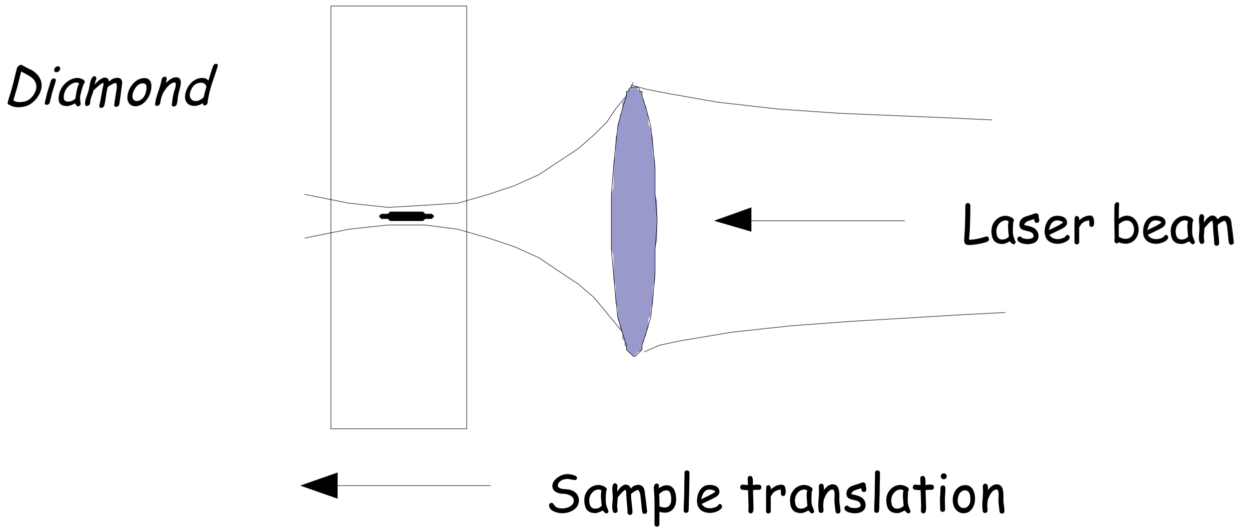
- Neuronal stimolation and bio-sensing
- Neuro-prosthetics (artificial retina)
- Muscular-prosthetics: interconection with artificial prostheses

Perspective 2. SoD MEA schematics

3D integration :
Bio-SOD

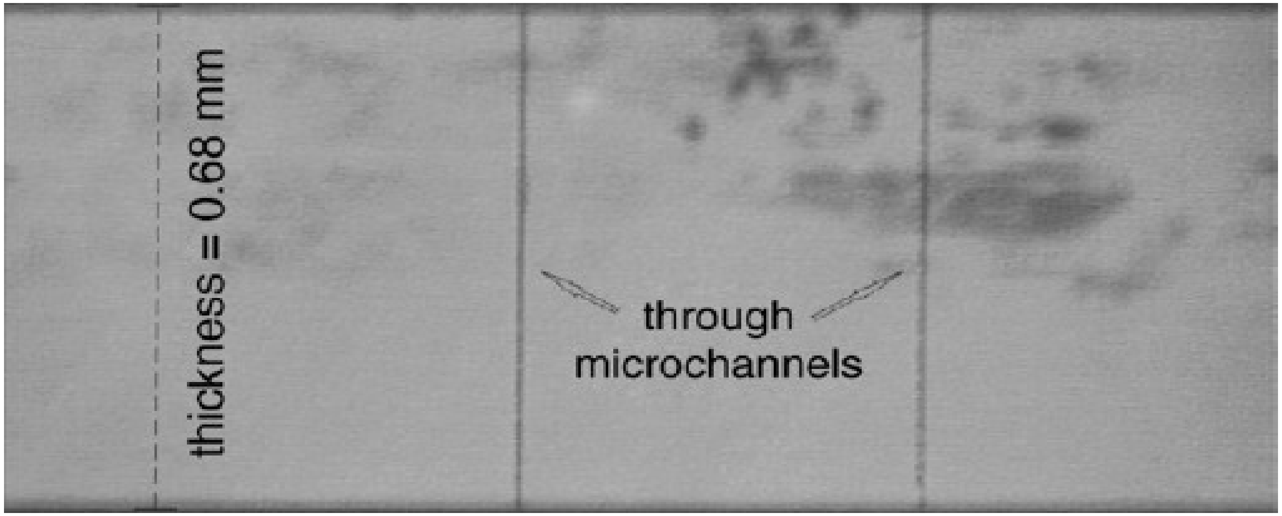


Through Diamond Vias?



Feasibility of graphitic vias by direct laser irradiation demonstrated*

Electrical properties to be verified!



*T.V. Kononenko et al., "Femtosecond laser microstructuring in the bulk of diamond," *Diamond and Related Materials*, **18**, (2009) 196-199

Collaboration

National Institute
for Nuclear Physics

University of Florence

INOA-CNR,Florence

European Laboratory
for Non Linear Spectroscopy
Florence

University of Perugia

IMM-CNR, Bologna

Politecnico di Bari

istituto italiano di tecnologia

Thank you for listening!