Status of the silicon on diamond technique and perspectives

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CARAT 2nd WS, GSI Darmstadt, December 14th 2010

Timetable

2007

- Laser enhanced Silicon-On-Diamond (SOD) bonding technique: INFN National Experiment RAPSODIA (2007-2009)
- Results presented at the 1st CARAT WS last year
- 2010: Research plan and preliminary studies on applications of **SOD for integrated radiation detectors and biosensors**
- **September 2010: INFN National Experiment CHIPSODIA (2011-2012) approved. Aim: Silicon Chip-On-Diamond bonding**

today

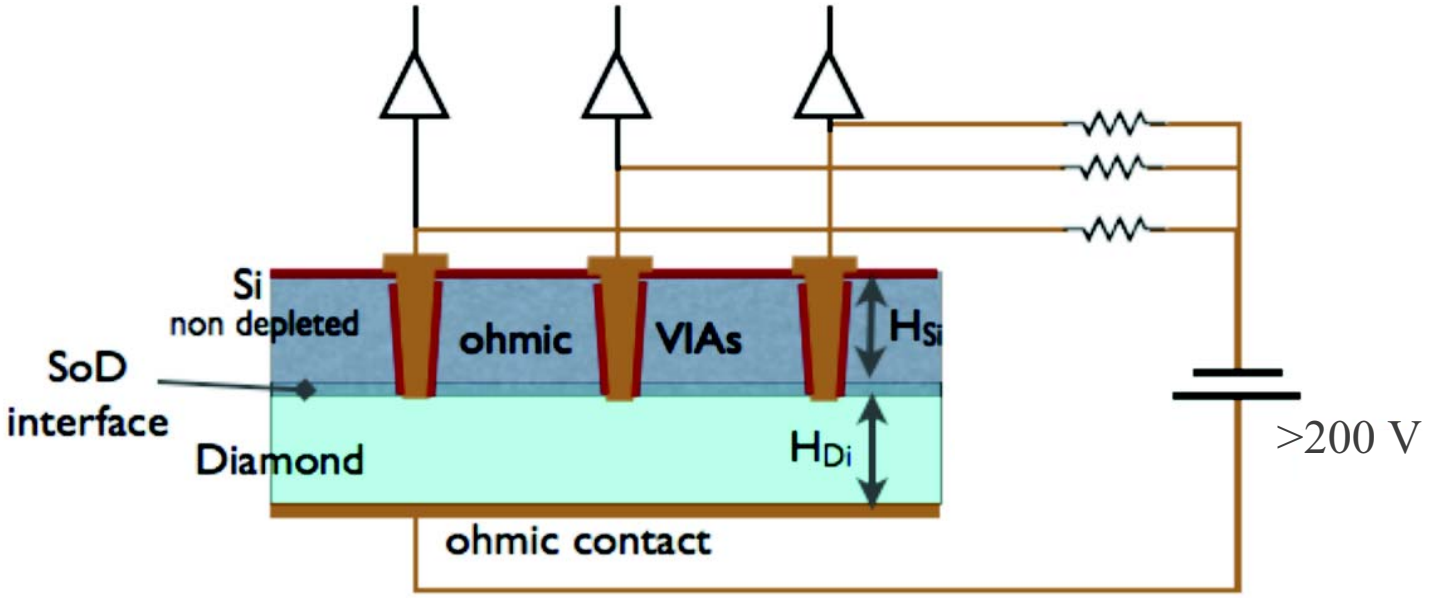
GSI 2nd CARAT WS

Results on:

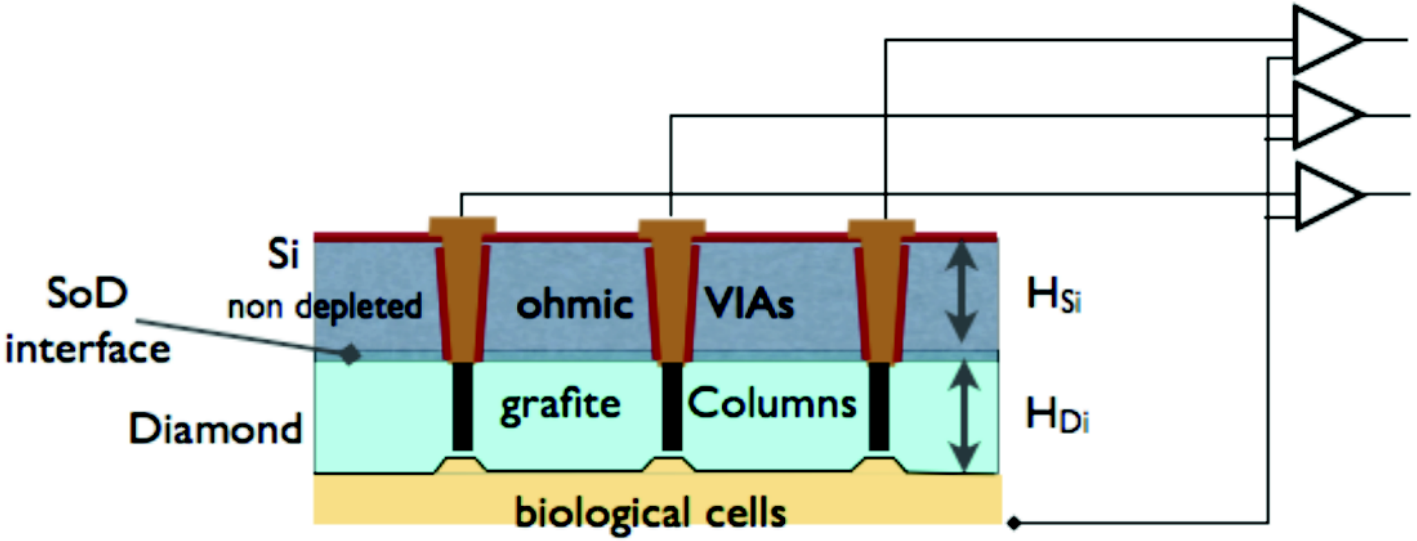
- Through Silicon Vias (TVS) fabrication on the silicon side
- Conductive graphitic channels through the diamond bulk

2012

CHIPSODIA (2011-2012) Two main research lines:



SOD detector
(not to scale)

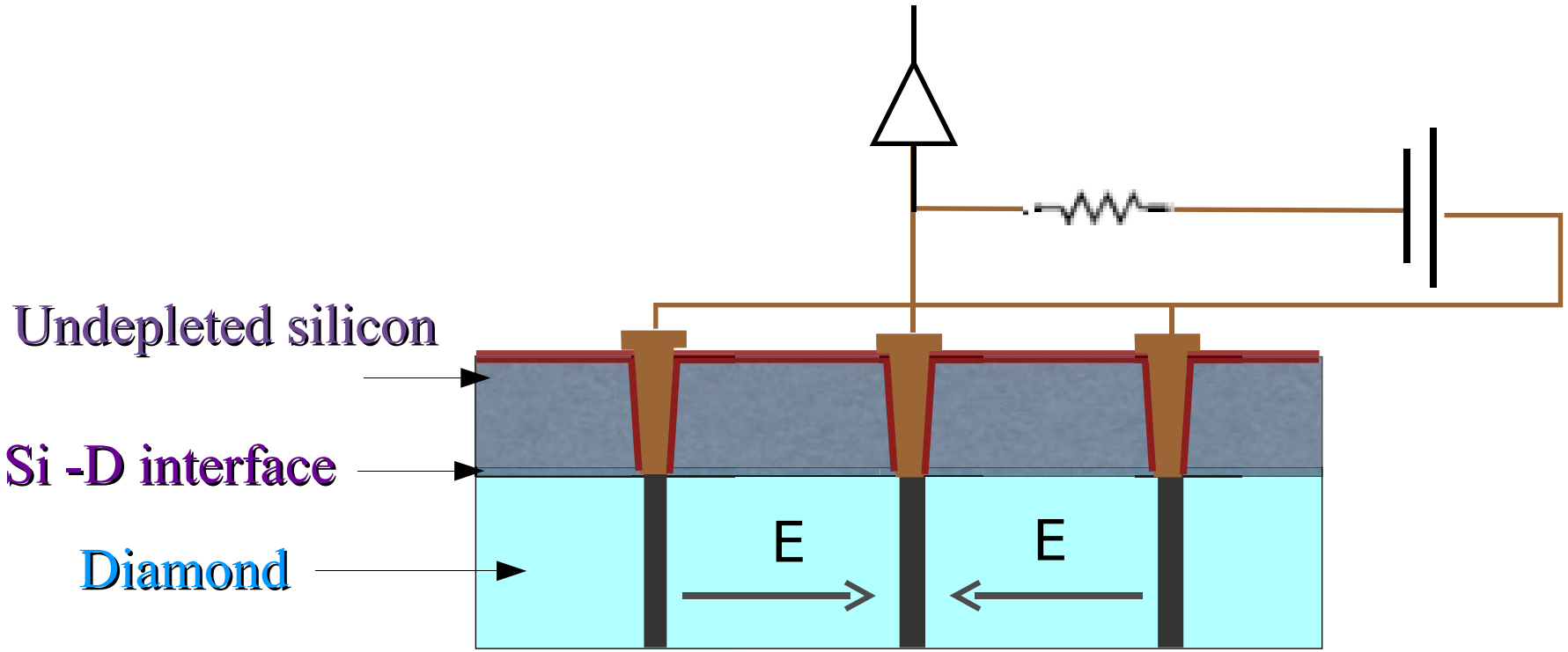


SOD biological
device
(not to scale)

Final goal: electronic circuits integrated on SOD silicon

MERGING THE TWO CONCEPTS

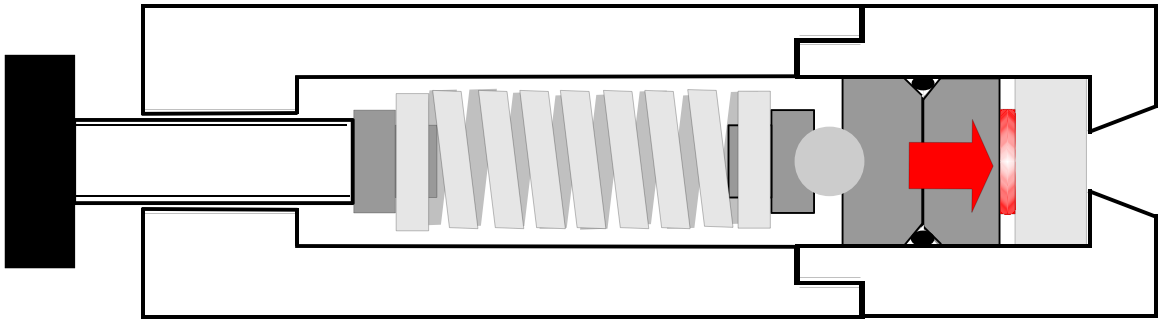
Detector and Biological devices technologies can be merged in a 3 D detector with graphite column electrodes

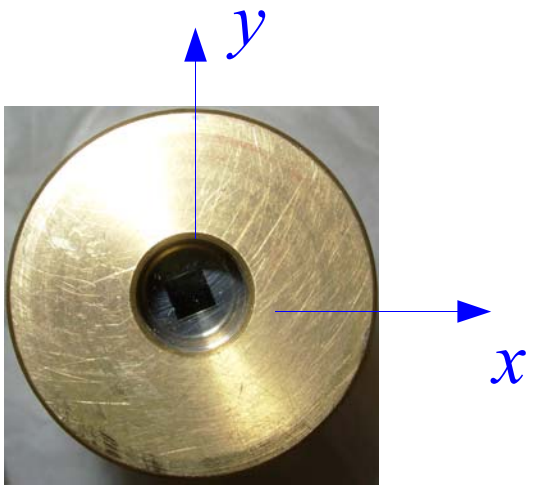


(not to scale)

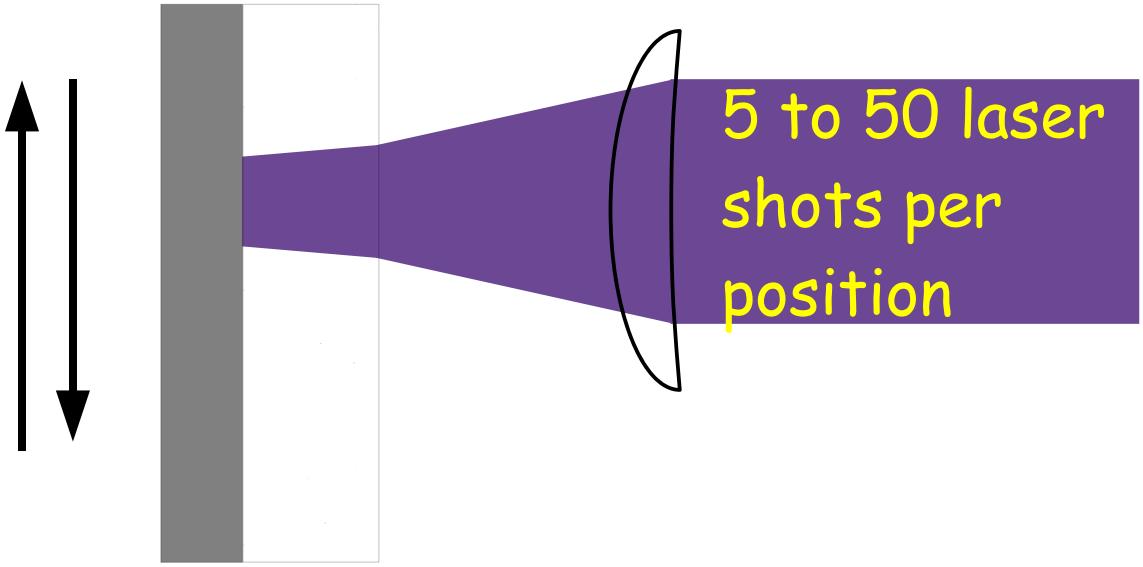
Summary of SOD technique and results

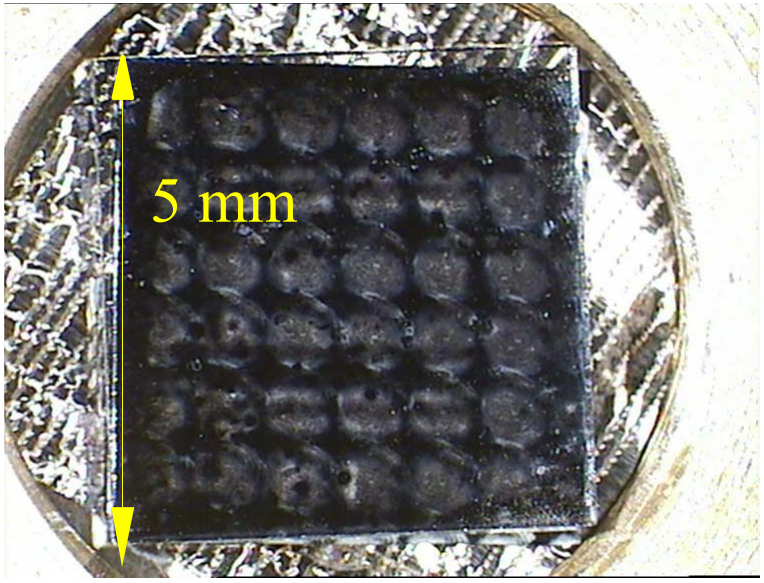
Sample holder on *xyz* linear stage
(controlled by PC in 2010)





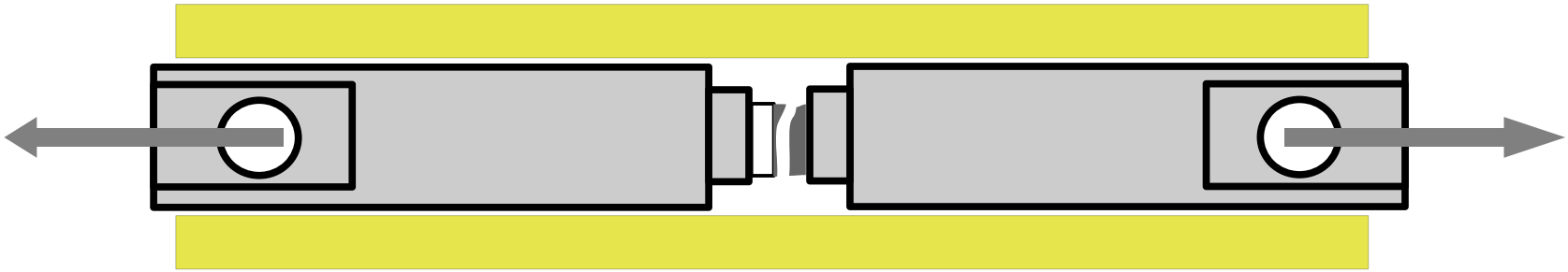
Silicon and diamond plates, under 80 Mpa uniaxial stress, irradiated by 20 ps-7ns 355 nm laser pulses, at 1 -10 J/cm^2 stopped within 10 nm of Si, causing melting of Si and diamond and formation of an amorphous/nanocrystalline SiC interface



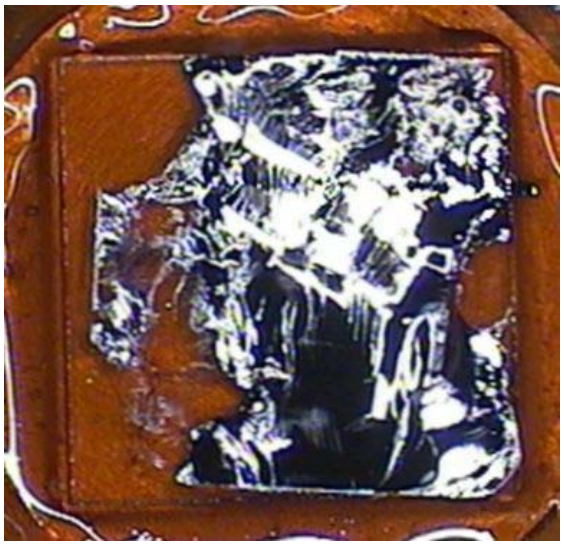


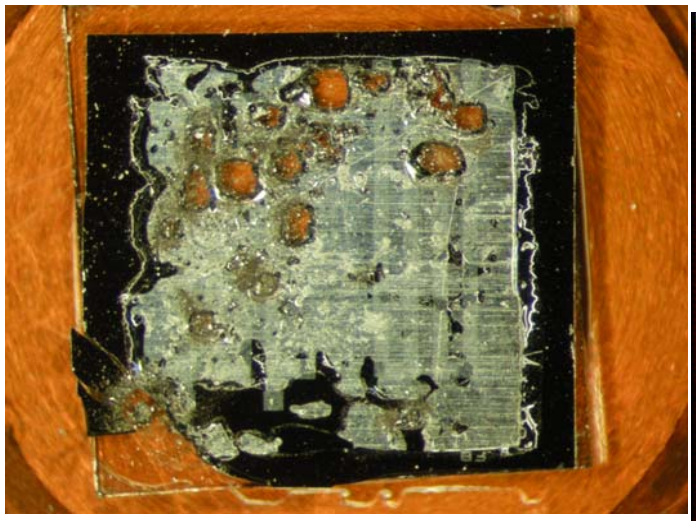
Summary of SOD preparation and measurements:

Mechanical strength: >60 kgp (24 MPa)



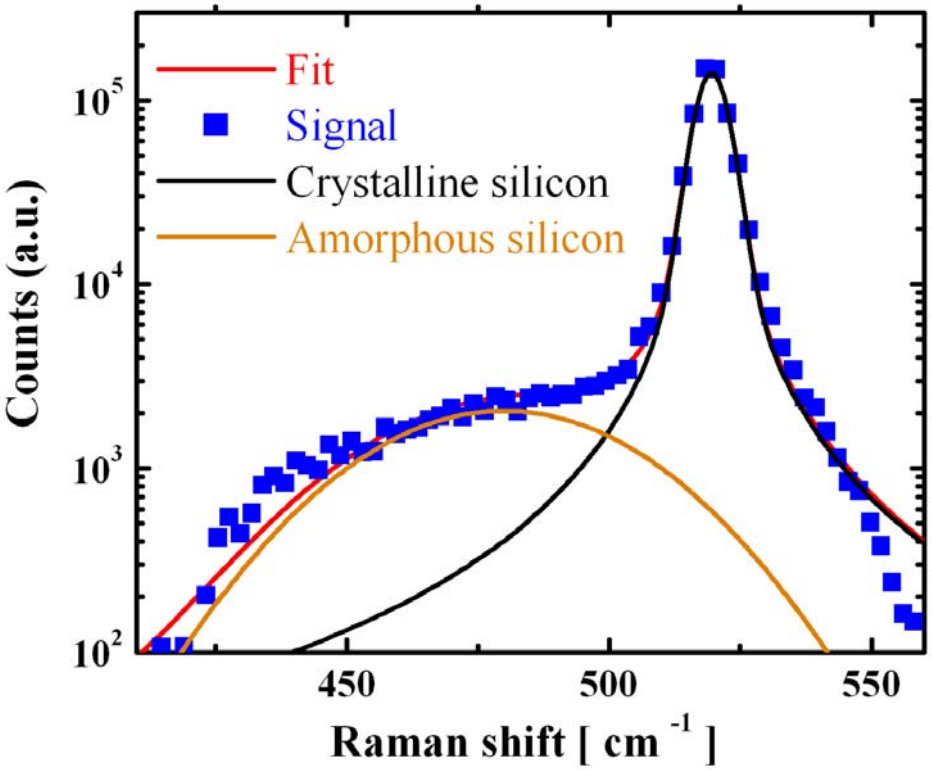
Si, epoxy resin or steel wire break, bonding (almost) intact



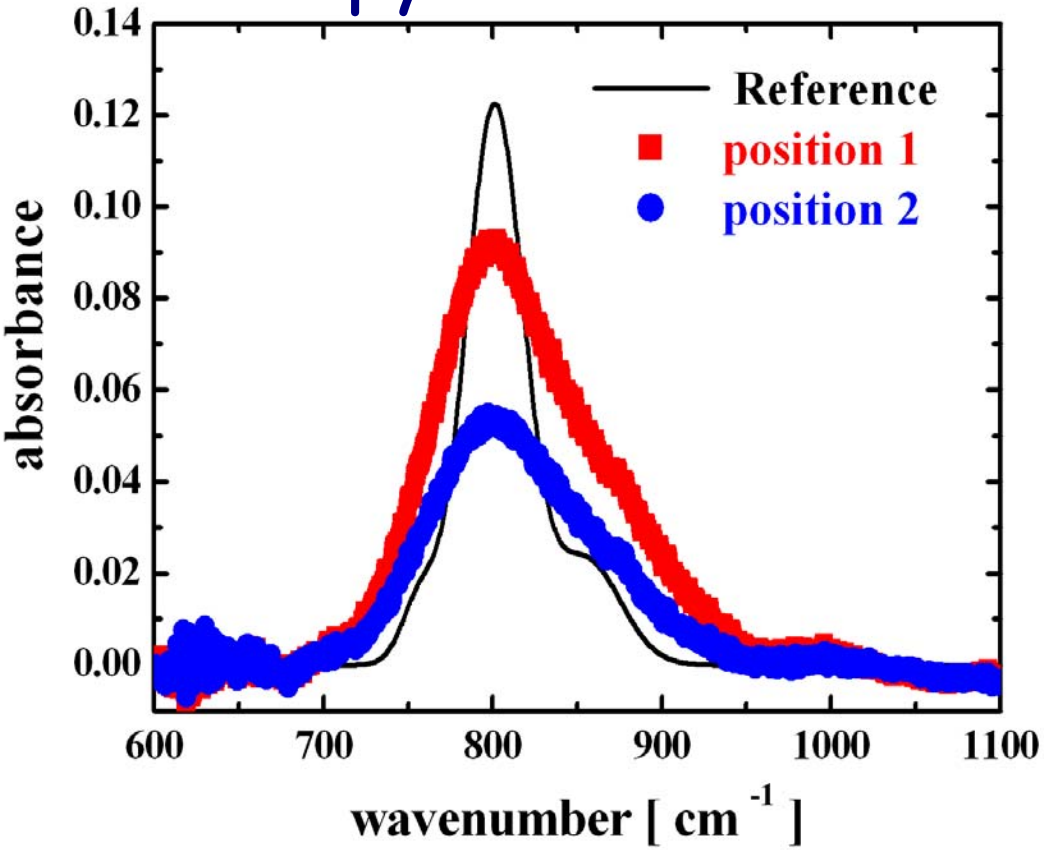


Summary of SOD preparation and measurements:

Optical Spectroscopy



Raman Spectroscopy:
Upper limit of amorphous silicon layer at the SOD interface: ~100 nm



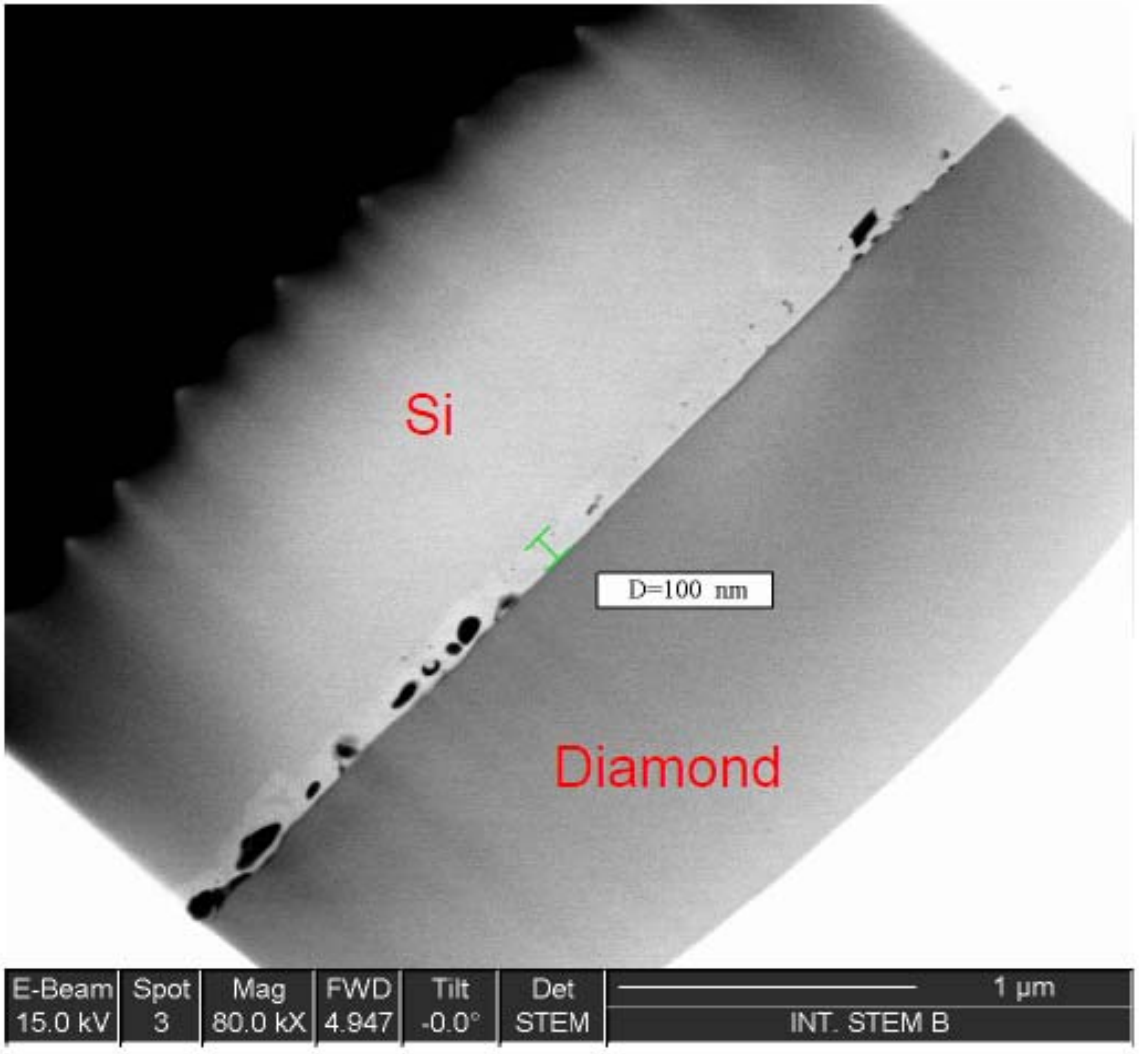
FTIR:
Nanocrystalline SiC*, from 50 nm to 3 nm depending on process parameters

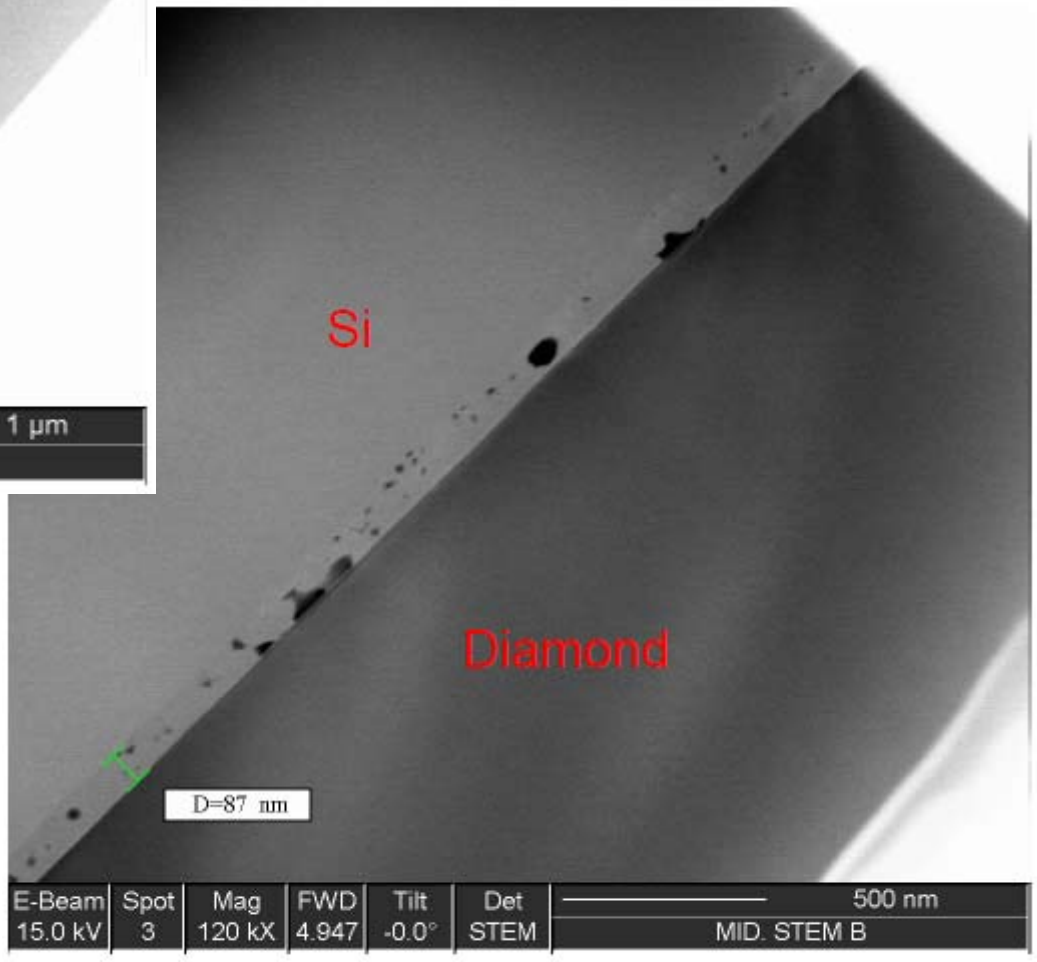
* Reference: M. Friedrich et al. *Phys. Stat. Sol.* (a)145, 369 (1994).

15 KeV STEM (SOD8)

(A. Scorzoni & S. Frabboni)

About 100 nm thick interface (three samples tested so far)





Spectroscopy evaluation and numerical simulation of interface thickness confirmed

Presence of cavities?

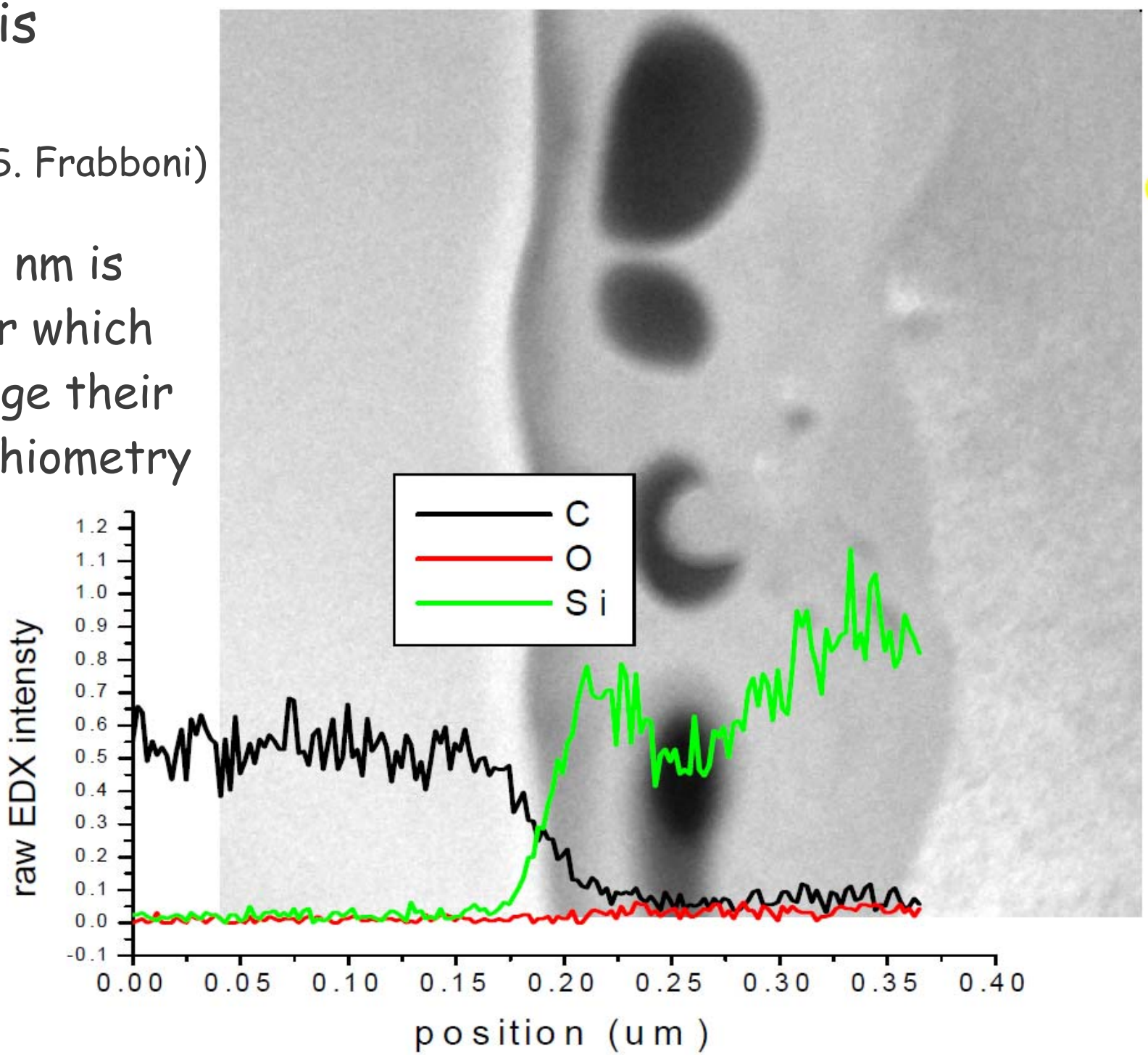
How to avoid it?

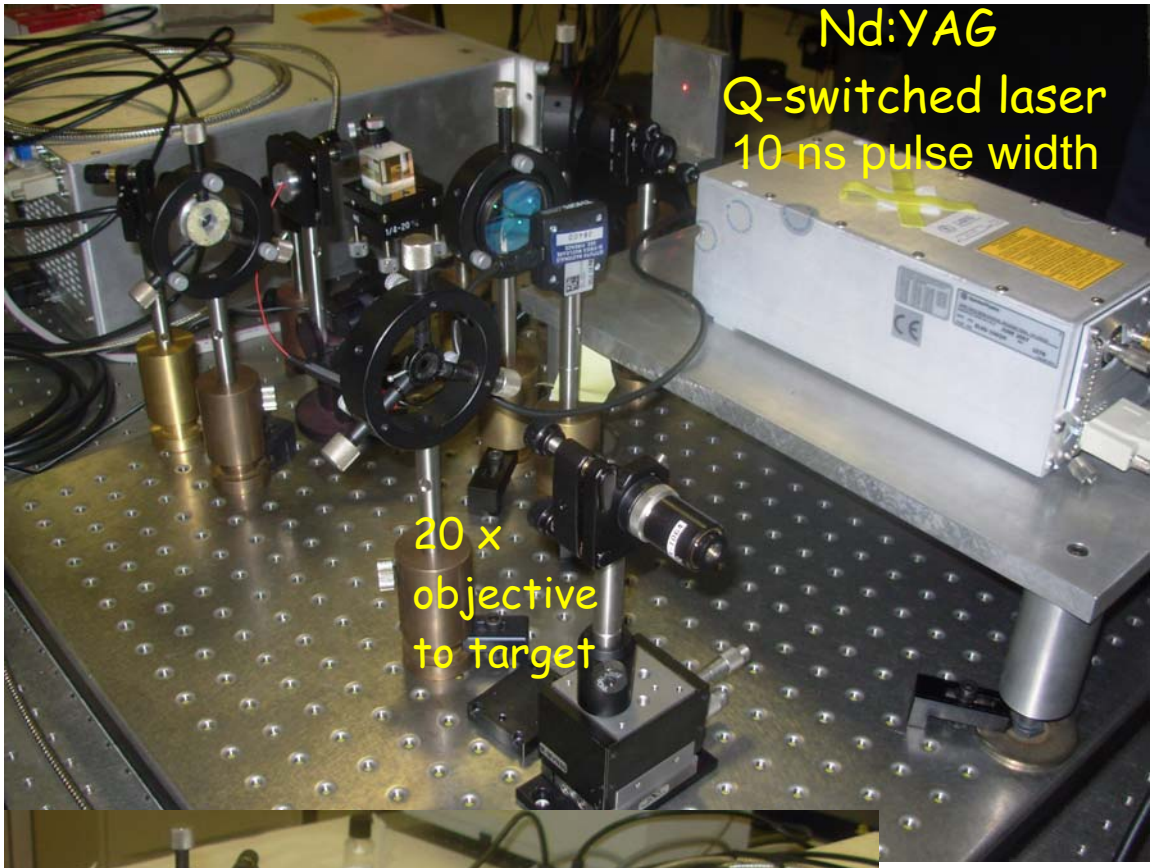
EDX analysis (SOD8)

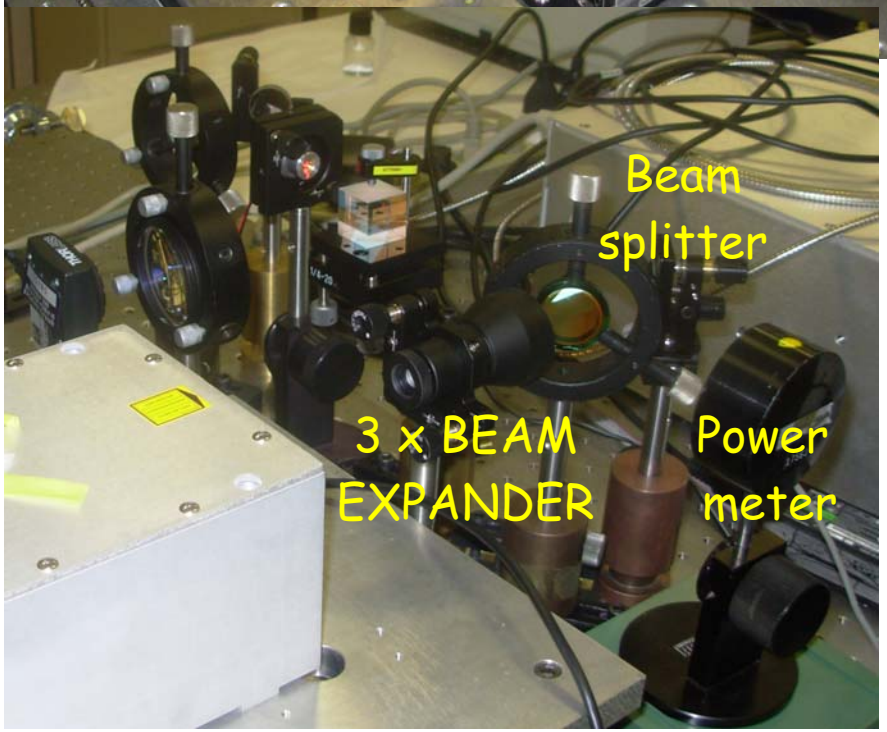
(A. Scorzoni & S. Frabboni)

A layer of 50 nm is observed over which Si and C change their relative stoichiometry

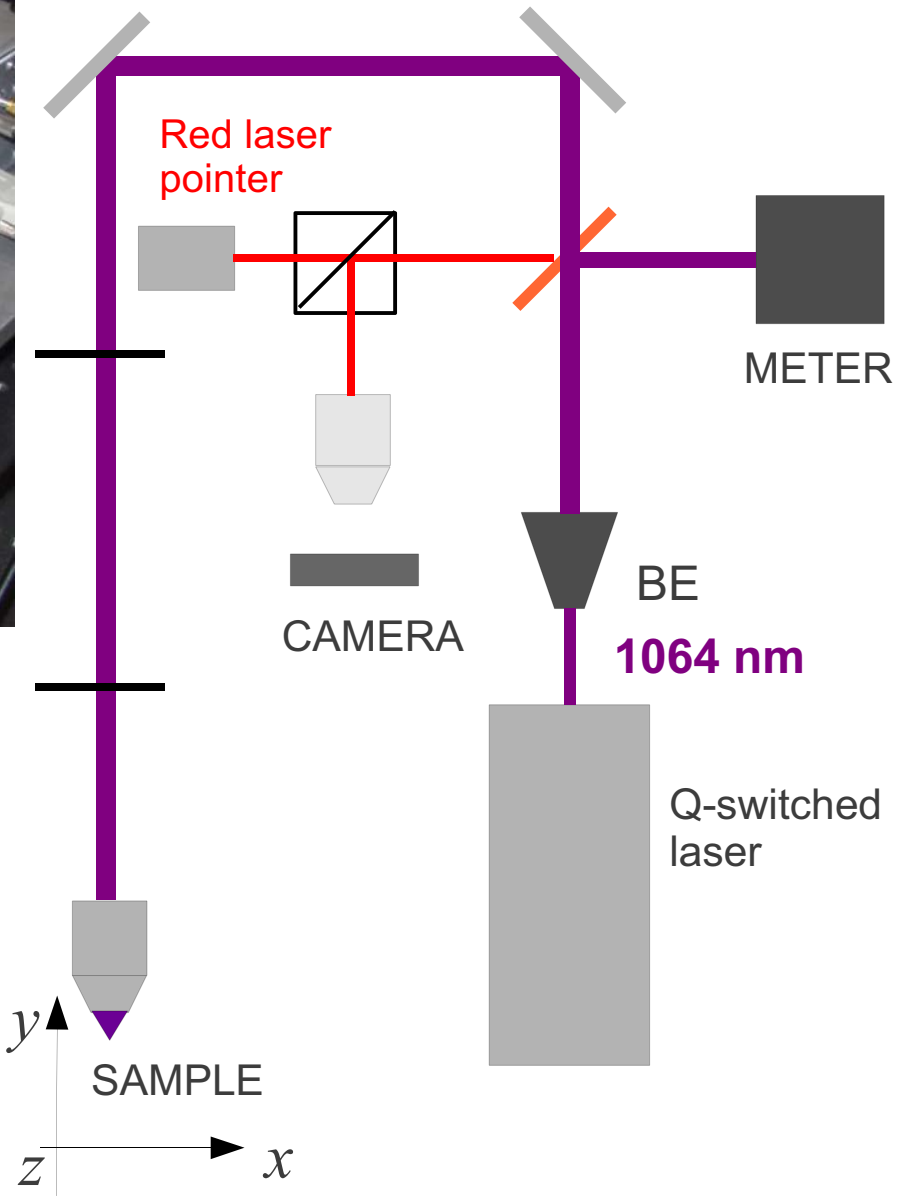
in agreement with FTIR results

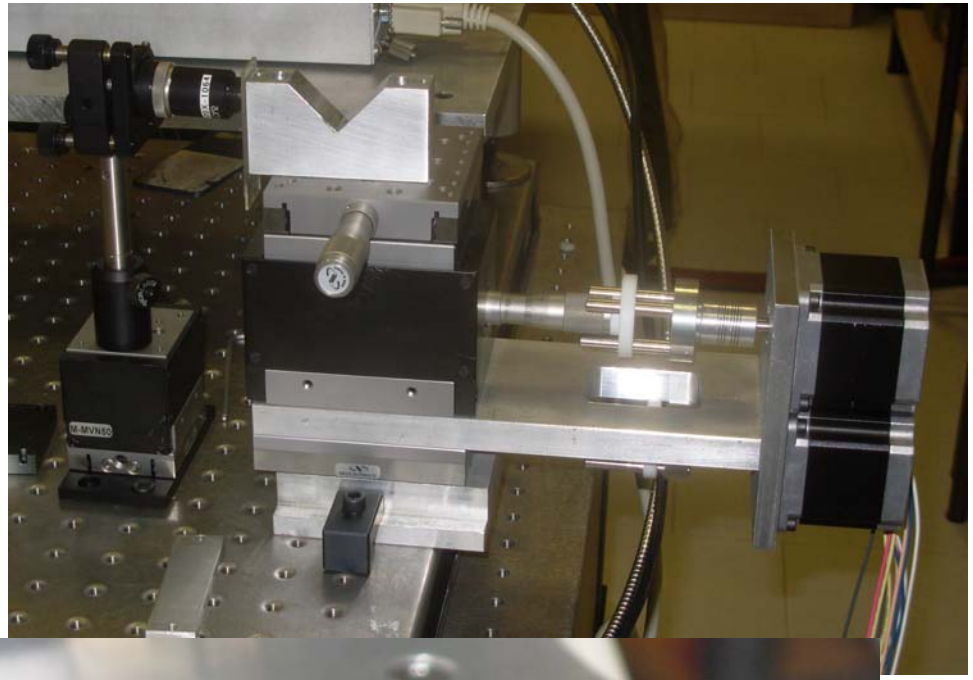






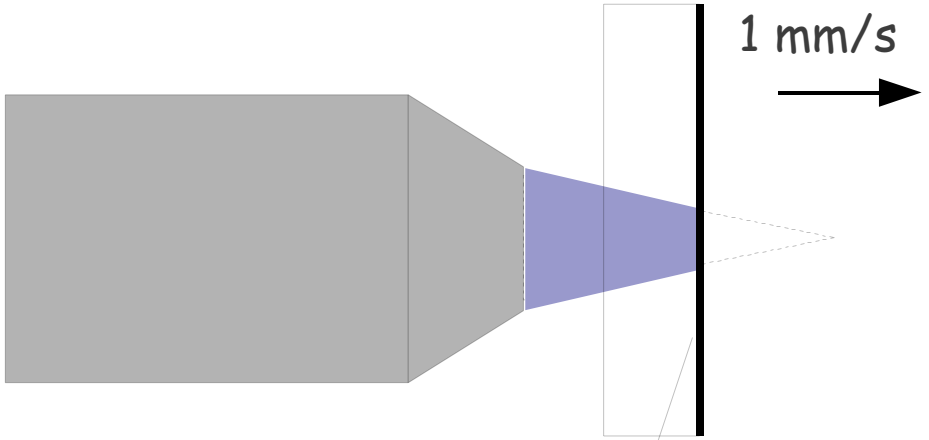
Graphitic Columns





Diamond sample

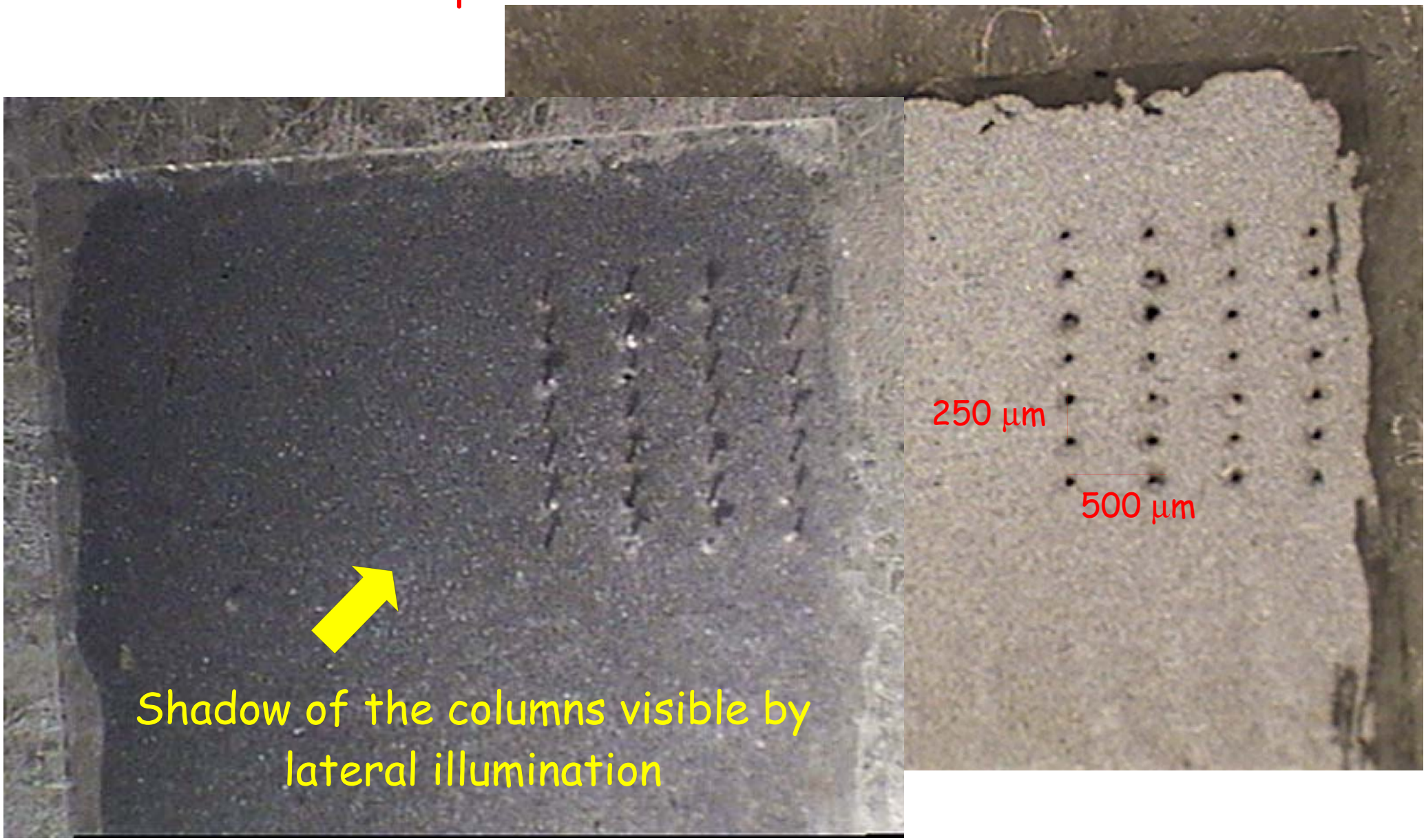
As the sample moved toward the effective focal plane diamond is turned to graphite through the sample thickness

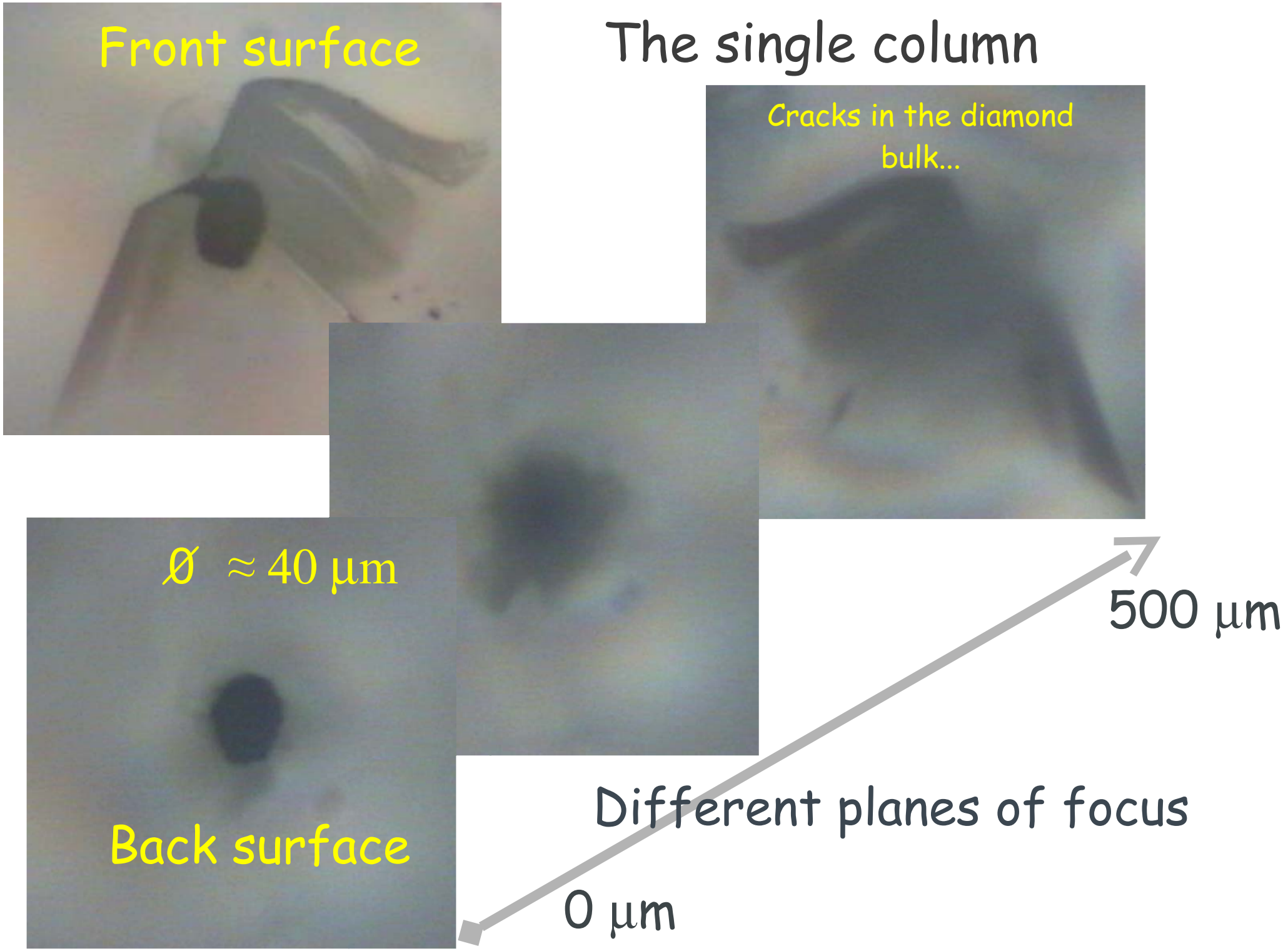


Silicon layer on the back if it is a SOD sample, or silver paste

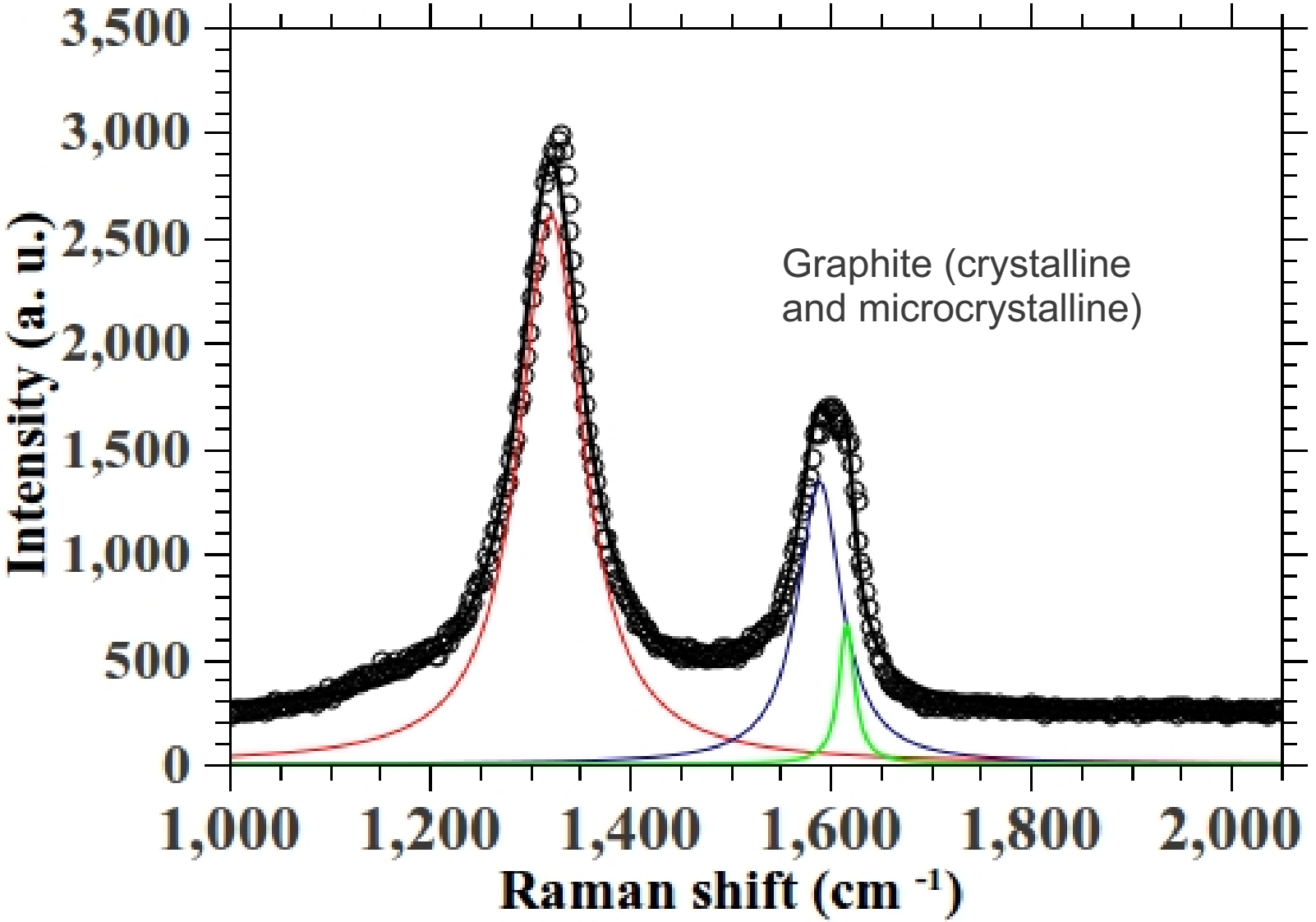
An opaque layer is needed to start the graphitization process

Matrix of columns on a diamond sample with silver paste on the back surface

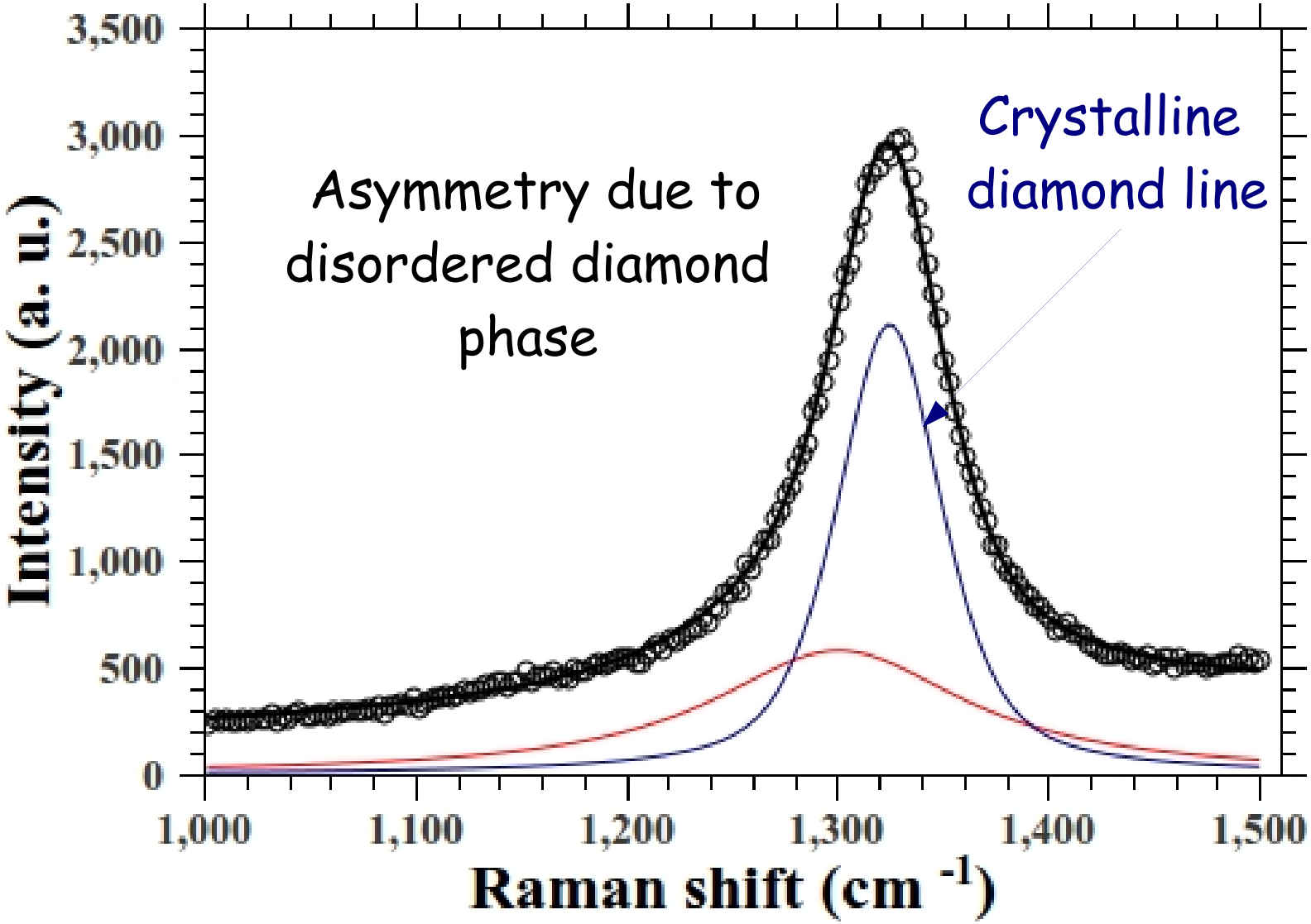



The single column
Front surface
Cracks in the diamond bulk...
Ø ≈ 40 µm
Back surface
500 µm
Different planes of focus
0 µm

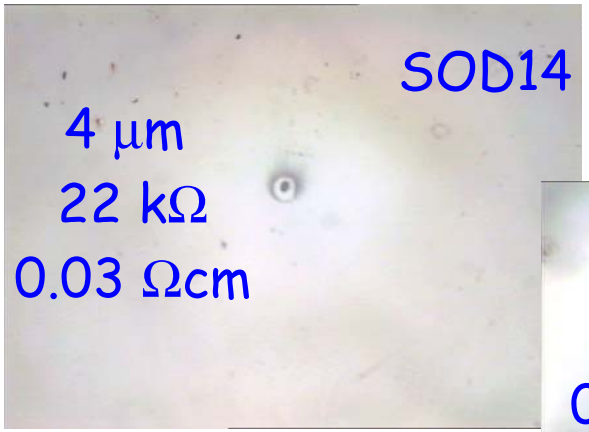
Raman spectrum of the graphitic columns

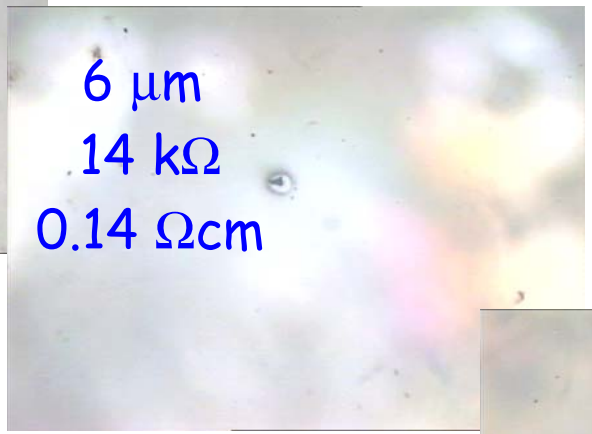


Raman spectrum of the graphitic columns (diamond signature)

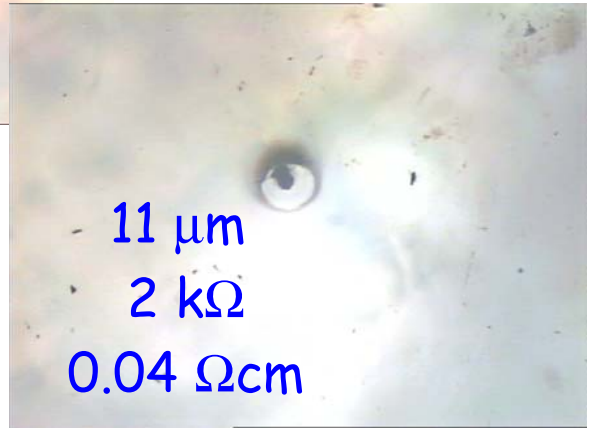


Electrical resistivity of the graphitic columns

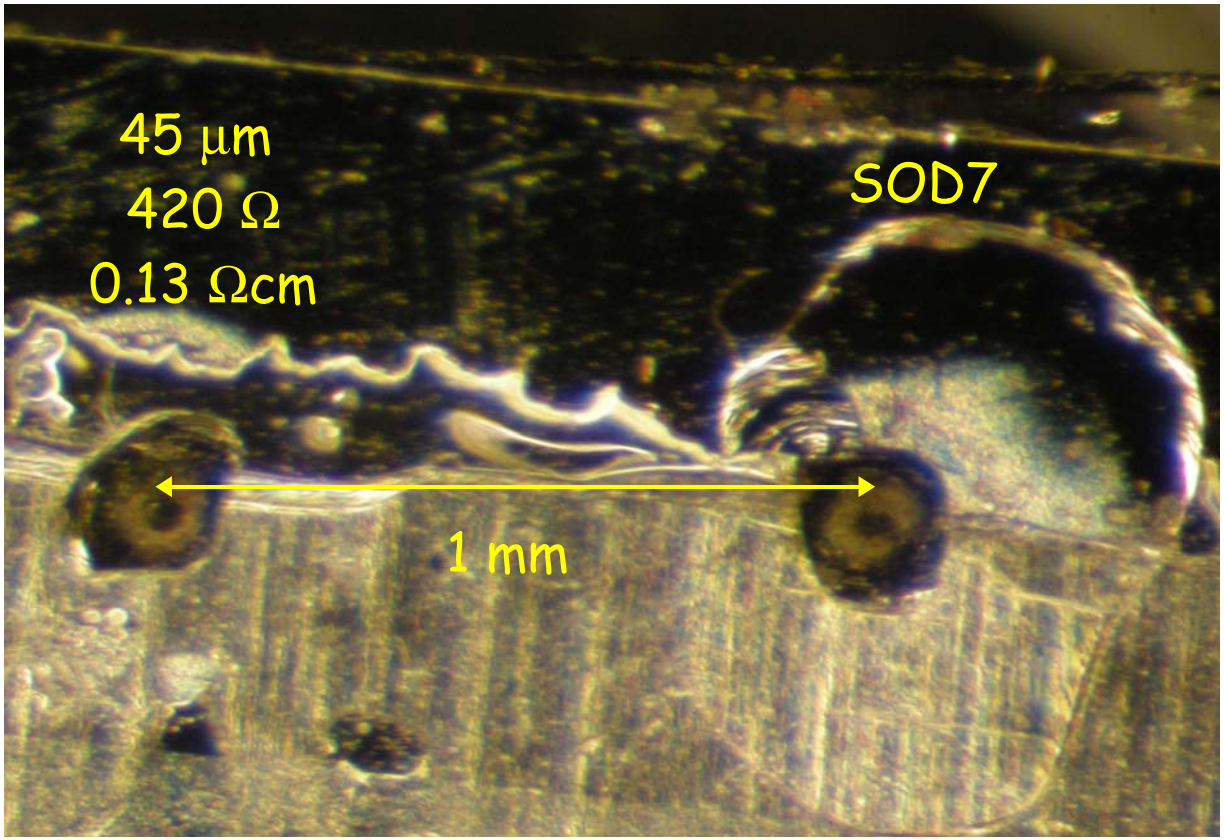




Diameter increasing with average energy



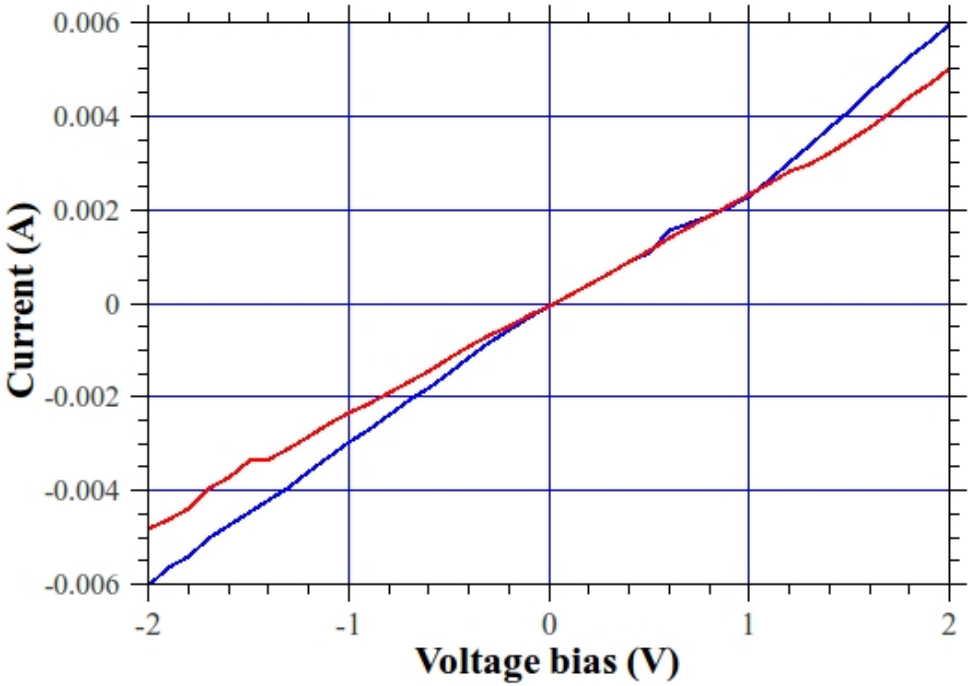
0.4 mm



Order of magnitude of resistivity quite constant

Electrical resistivity of the graphitic columns

SOD7 , R = 420 Ω

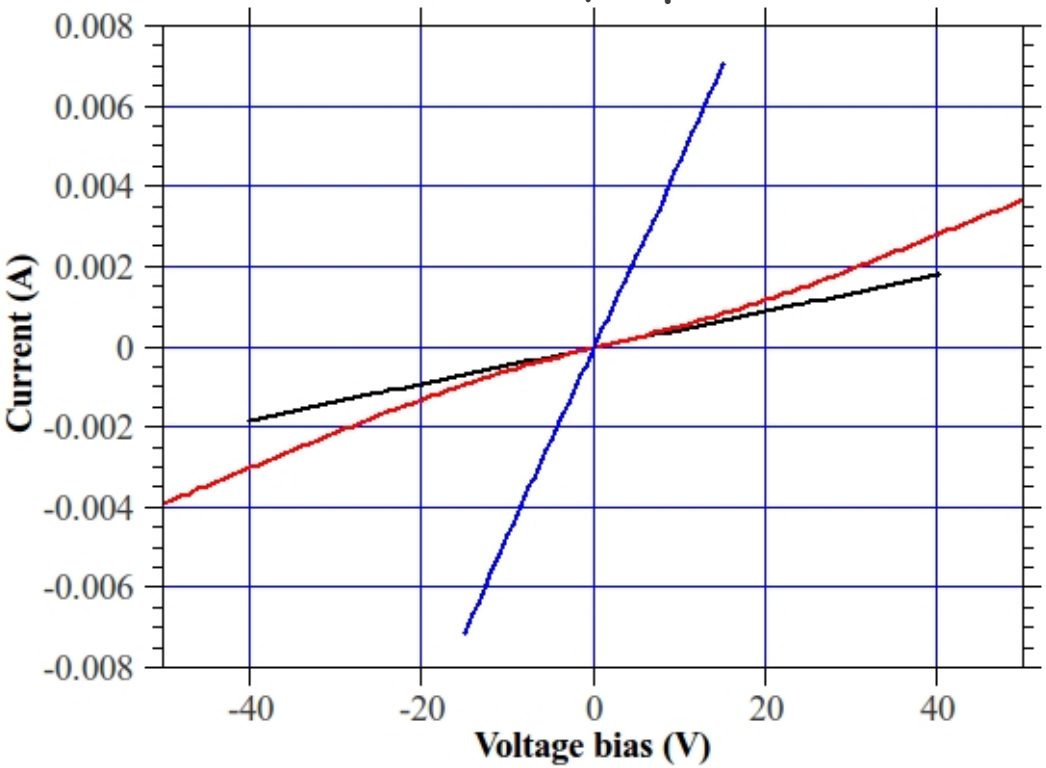


SOD14

R = 2 kΩ,

R = 14 kΩ, E = 2 μJ/pulse,

R = 22 kΩ, E = 1 μJ/pulse



We will investigate:

- the role of different process parameters as wavelength (NIR to UV) and pulse width (10 ns-100 fs)

- The diamond-graphite electrical contact

Drilling of through via in silicon wafer

Percussion drilling of a 50 μm thick Si wafer is performed in air with

- a 20 ns KrF excimer laser at 248 nm
- a 60 ps frequency quadrupled Nd:YAG laser at 266 nm

both a 20 Hz

20 ns irradiation shows:
A ten fold increase of the ablation efficiency passing from a spot diameter of 220 μm to 9 μm
at constant fluence
in the range 7.5 J/cm^2 to 13.2 J/cm^2.

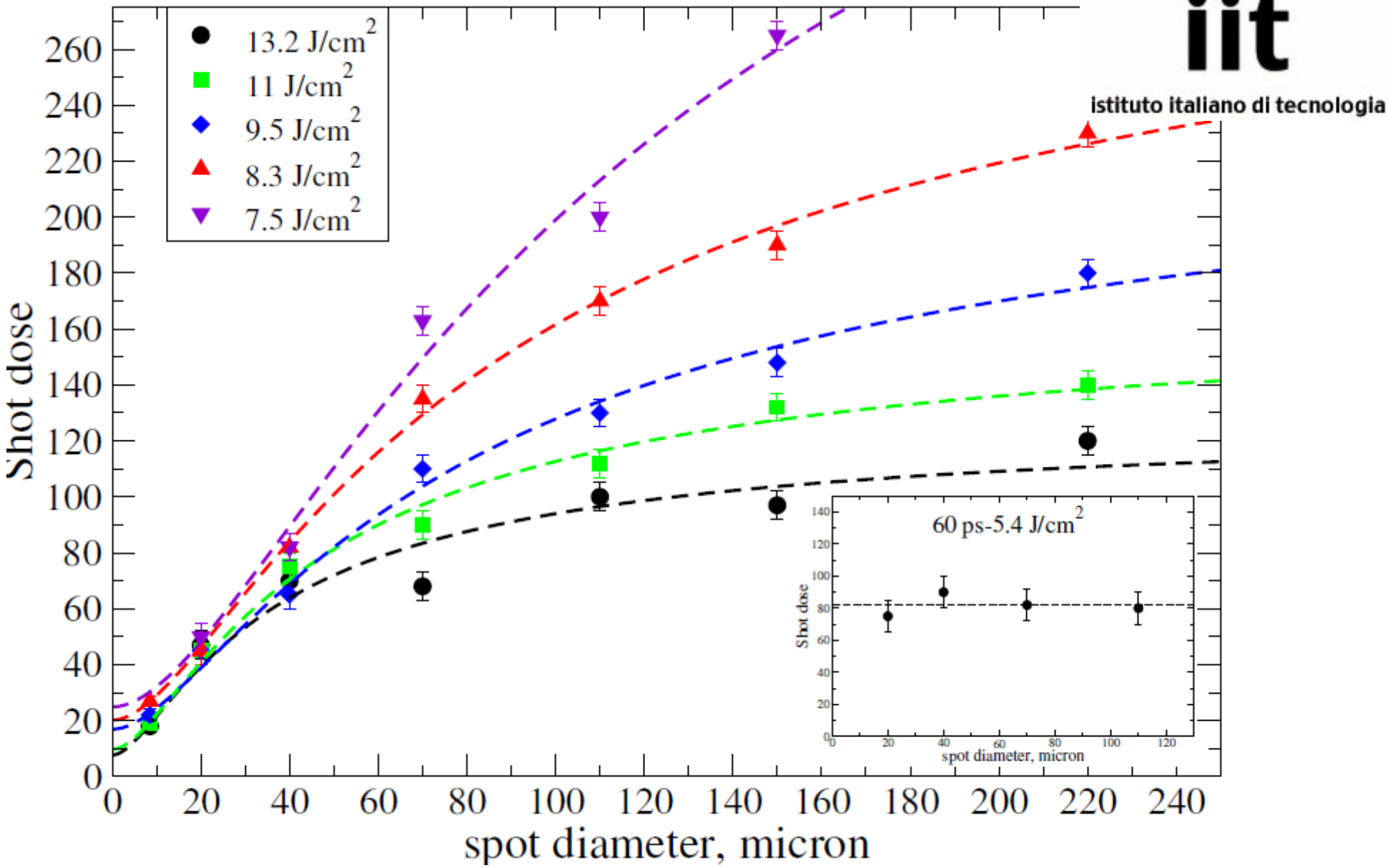
When using deep-UV ps pluses this spot size effect is not observed

Very large spot size effect in nanosecond laser drilling efficiency of silicon
F. Brandi,N. Burdet, R. Carzino, and A. Diaspro

Nanophysics Group, Italian Institute of Technology, Via Morego 30, Genova, Italy
25 October 2010 / Vol. 18, No. 22 / OPTICS EXPRESS 23491

Through Silicon Vias (TVS)

Excimer 248 nm, 20 ns laser & Nd:YAG 4th harmonic 266 nm 60, ps



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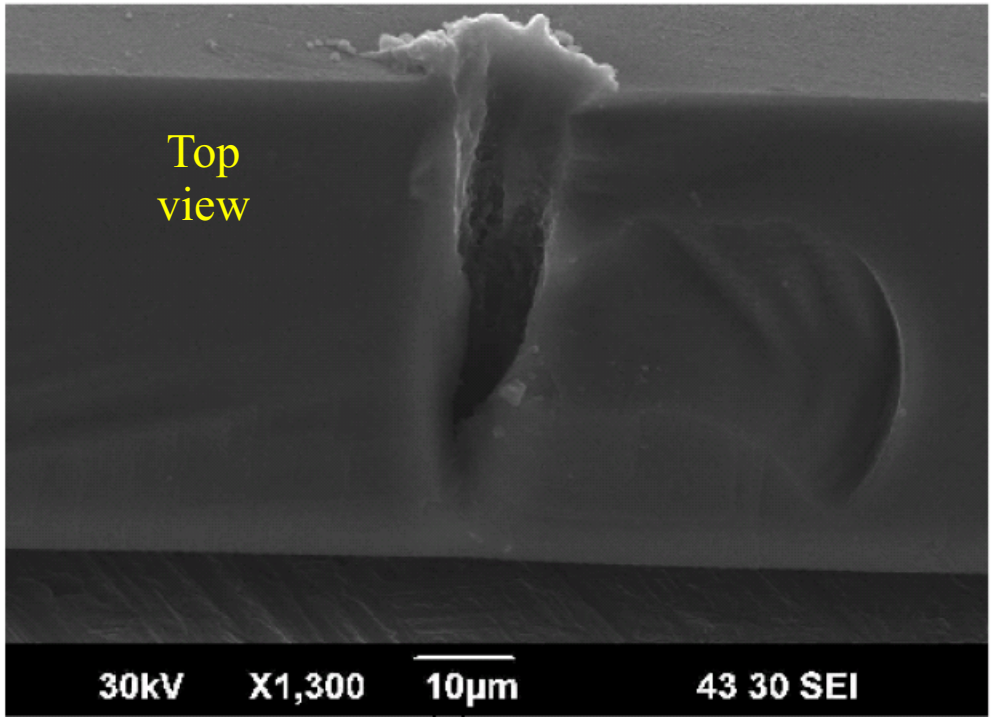
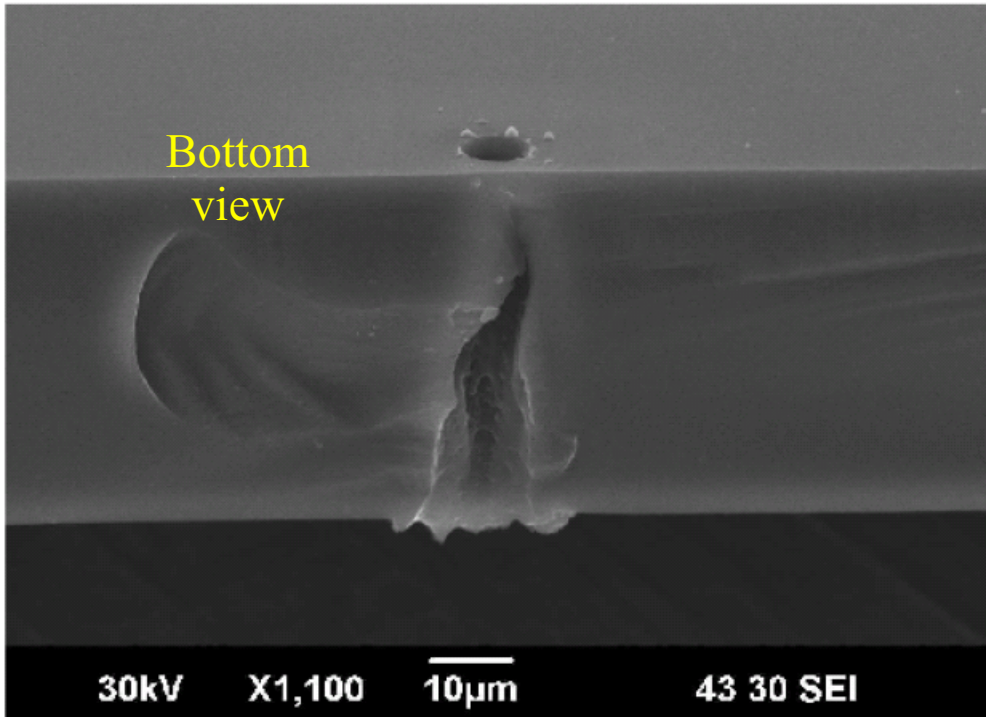
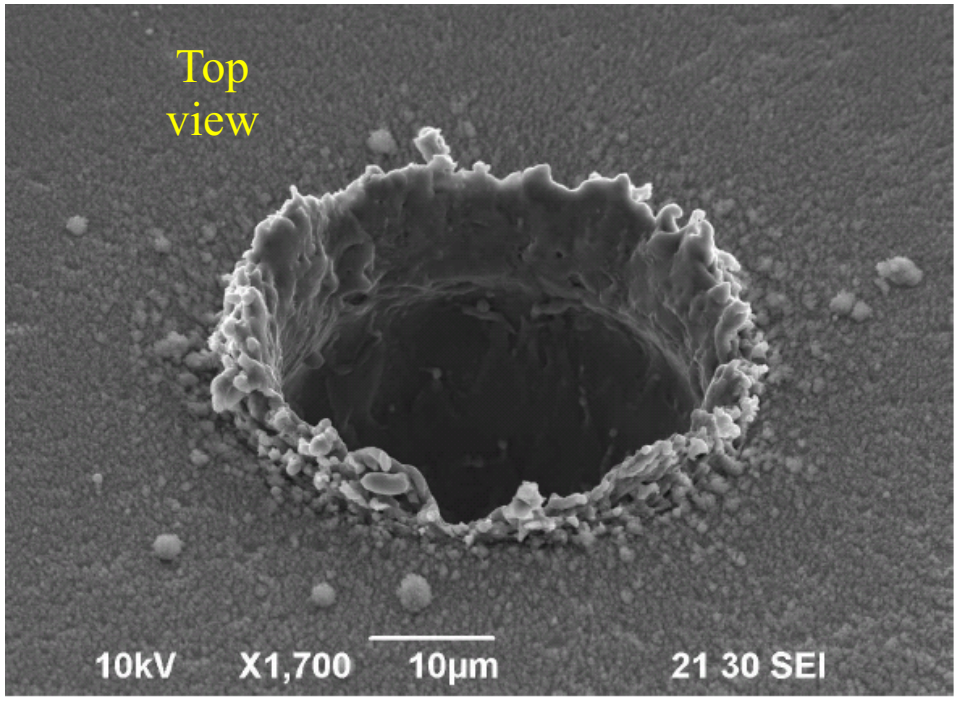
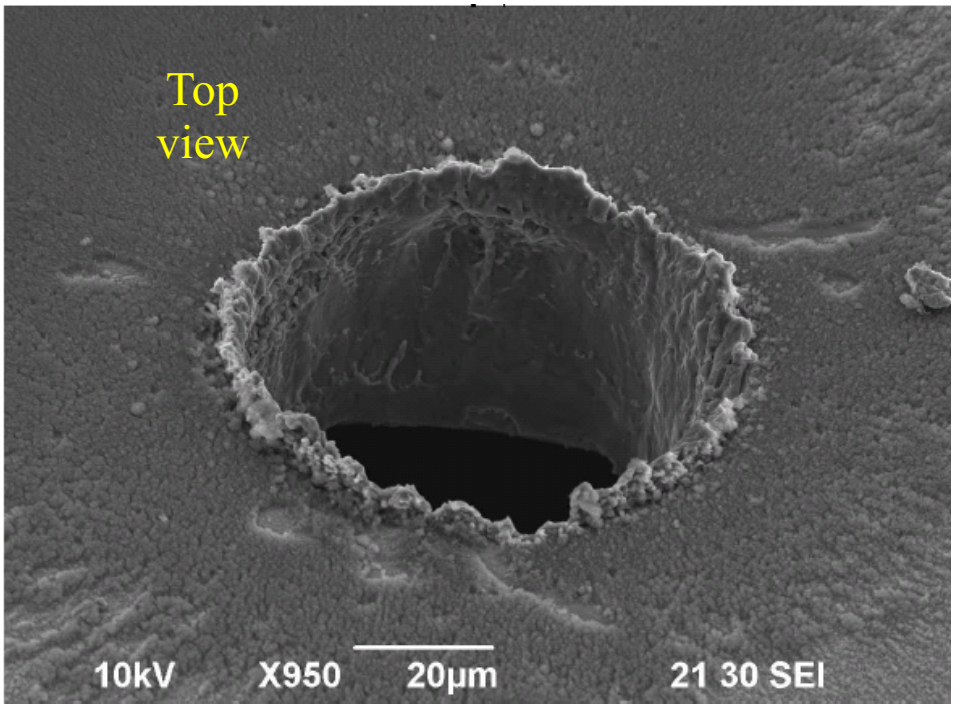
11 J/cm^2


Top
view
30kV X1,300 10µm 43 30 SEI

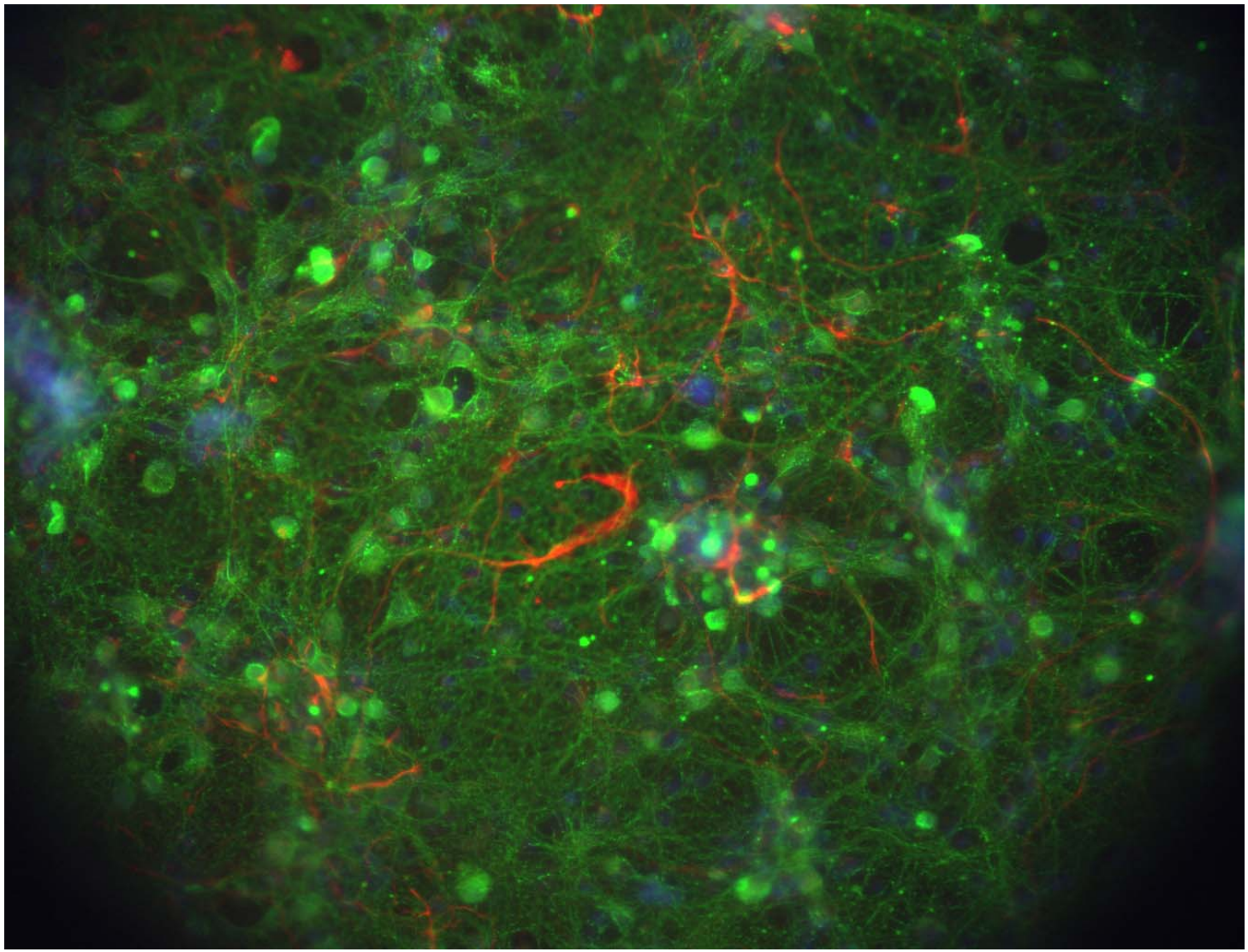

Bottom
view
30kV X1,100 10µm 43 30 SEI


Top
view
10kV X1,700 10µm 21 30 SEI


Top
view
10kV X950 20µm 21 30 SEI

Rat embryo culture (hippocampus) kept for three weeks on diamond by polylysine adhesion

Images obtained by staining with fluorescent dies by epifluorescence microscopy



Blue: nuclei

Green: tubulin

Red: glial cells

Thanks to
Dott Silvia Dante

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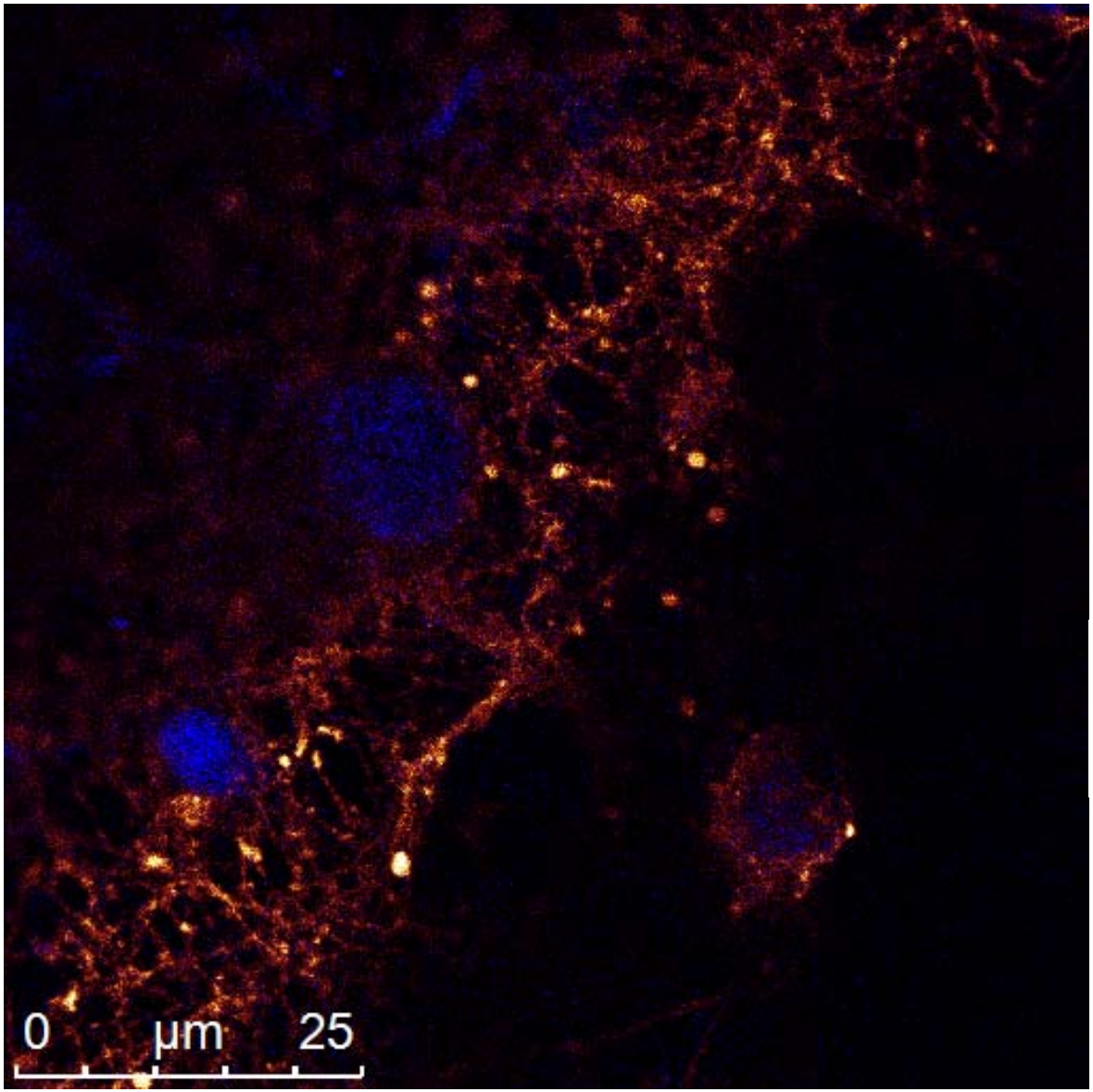
Rat embryo culture (hippocampus) kept for three weeks on diamond by polylysine adhesion

Images obtained by staining with fluorescent dies by confocal microscopy



Blue: nuclei

Red: tubulin

Thanks to
Dott. Paolo Bianchini

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Issue to be addressed in 2011

TSV: electrical insulation/conductivity, aspect ratio, silicon damage

Graphitic columns: conducibility, aspect ratio, diamond damage

TSV-diamond ohmic contact at the SOD interface

Functionalization of the diamond surface to host living cells

Contact between graphitic columns and living cells

MAPS chip on diamond and functionality tests

Feasibility of 3D diamond detectors

Collaboration

Italian National Institute for Nuclear Physics

Florence, Bari, Perugia

University of Florence

INOA-CNR,Florence

European Laboratory
for Non Linear Spectroscopy
Florence

University of Perugia and IMM-CNR of Bologna

Status of the silicon on diamond technique and perspectives

Thank you for listening!

CARAT 2nd WS, GSI Darmstadt, December 14th 2010