INFN

Silicon On DIAmond CHIP concept (CHIPSODIA)

iit
istituto italiano di tecnologia

INO-CNR

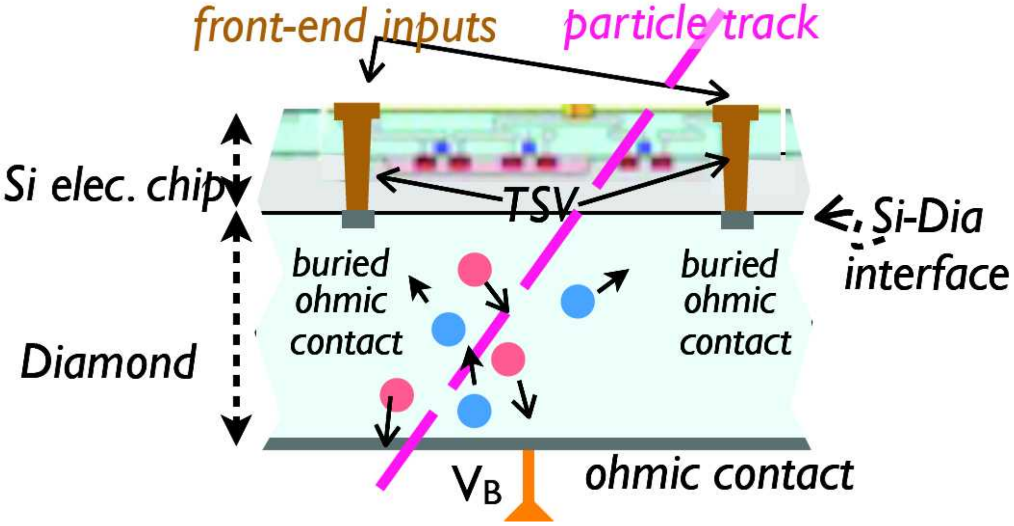
LENS

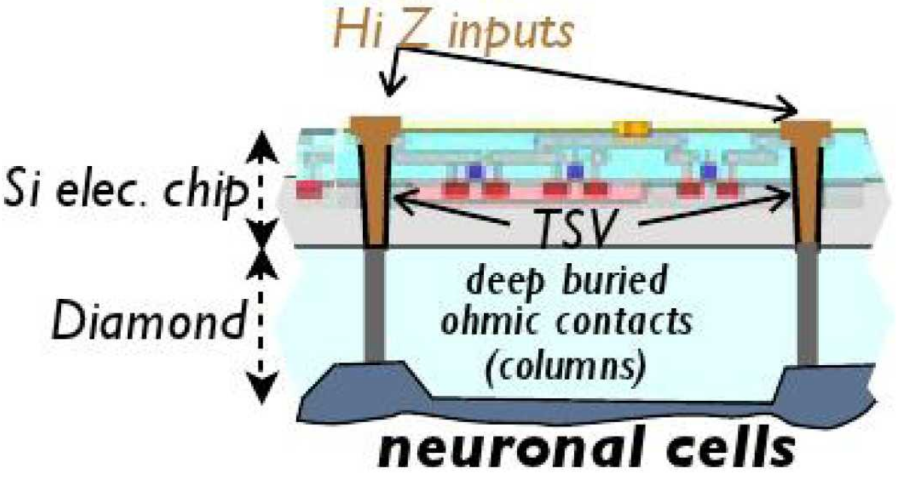
Silvio Sciortino, Giuliano Parrini,
Stefano Lagomarsino
for the CHIPSODIA experiment

Firenze, June 4-8 2012 INFN

CHIPSODIA aims at two prototypes

Proof of concept within 2012

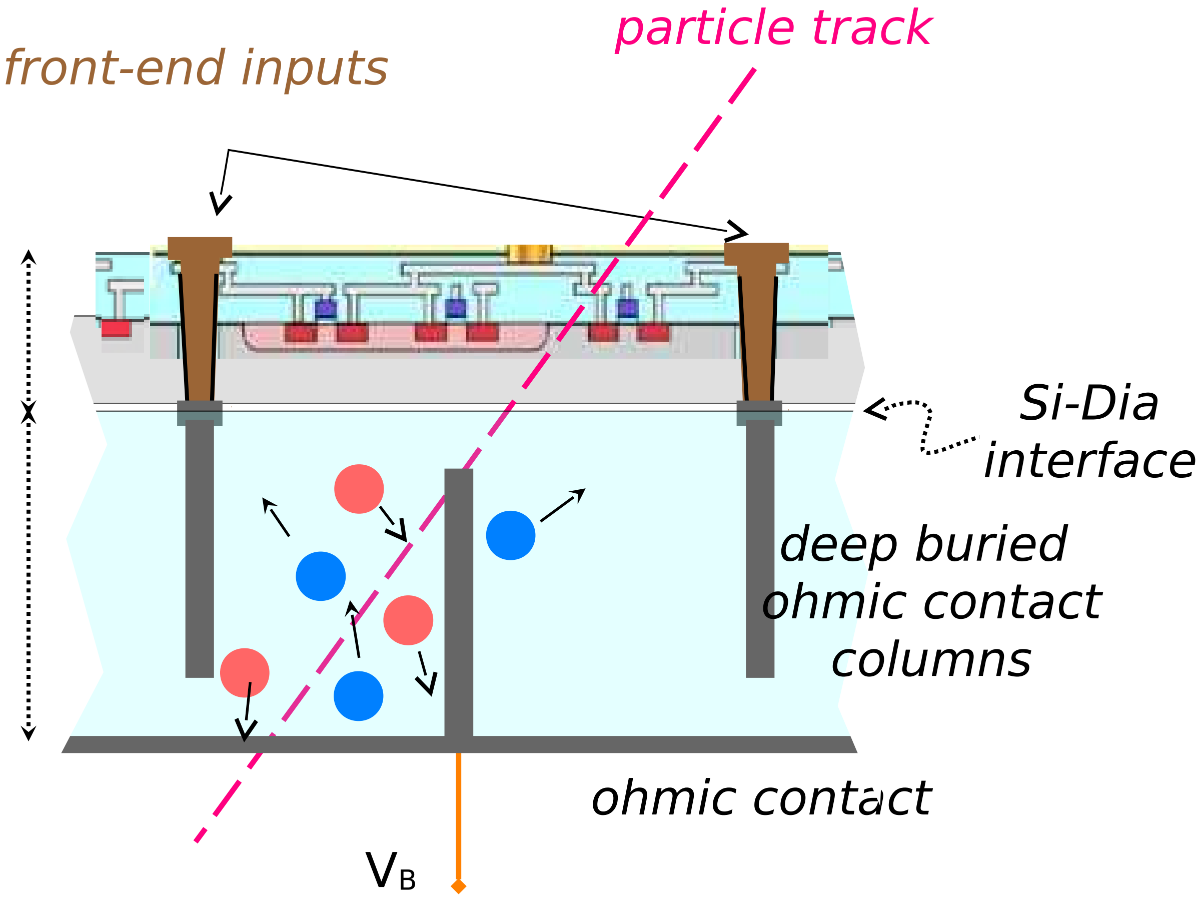




a) Chip-On-Diamond Sensor: diamond connected to the readout electronics by Through Silicon Vias (TSV).

b) SOD Micro-Electrode Array (MEA): diamond hosting neural tissue connected to the R/W electronics by conductive channels and TSVs

Feasibility of a 3D structure is also investigated



3D detector

Main issues

Silicon to Diamond Bonding and Characterization

Chip bonding to diamond plates

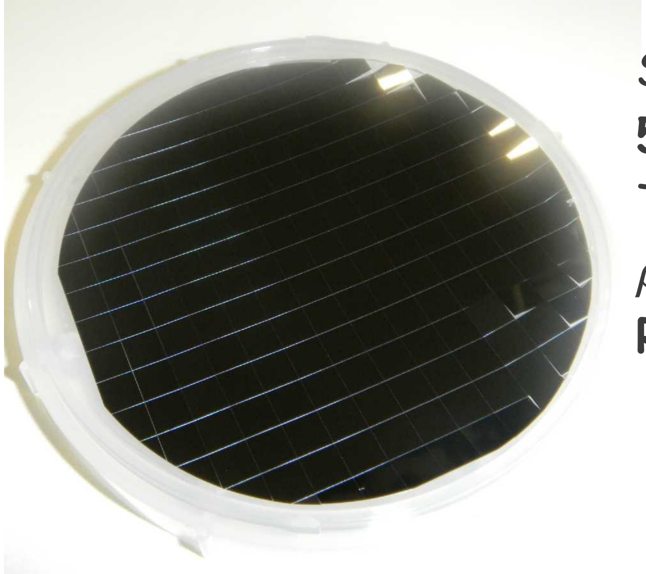
Connection of the die electronics to the diamond surface

Growing ohmic contacts by laser graphitization on the diamond surface

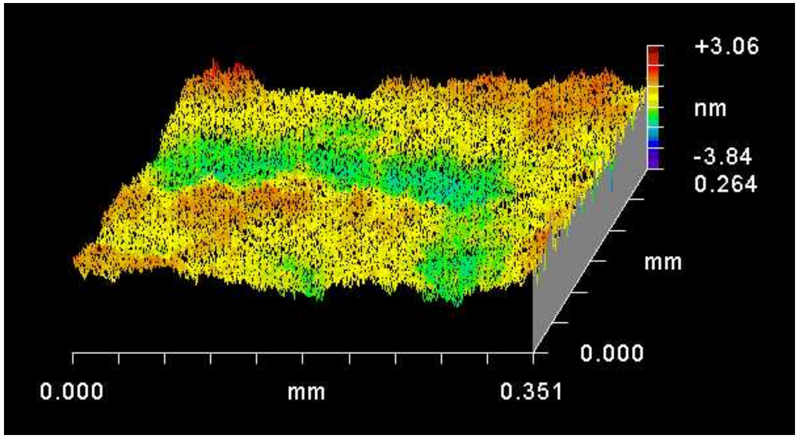
Growing grathitic channels through the diamond bias

Functionalization of the diamond surface and implantation of neural cells for MEA applications

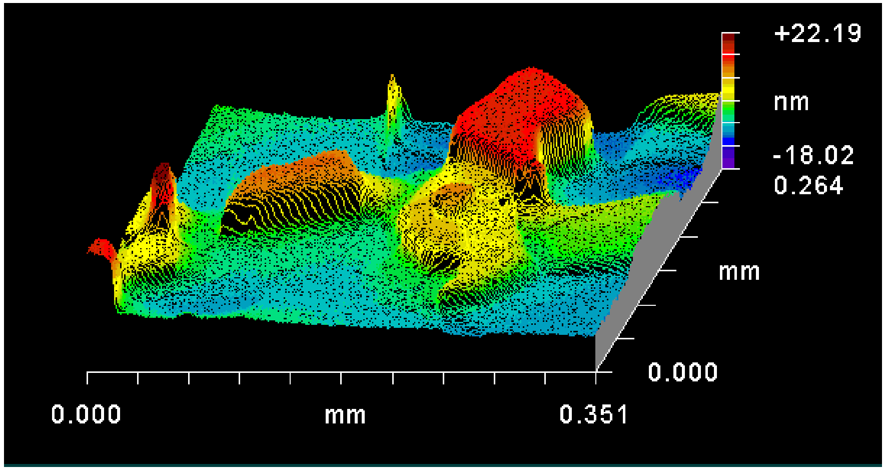
Silicon On Diamond Fabrication: Si & D samples



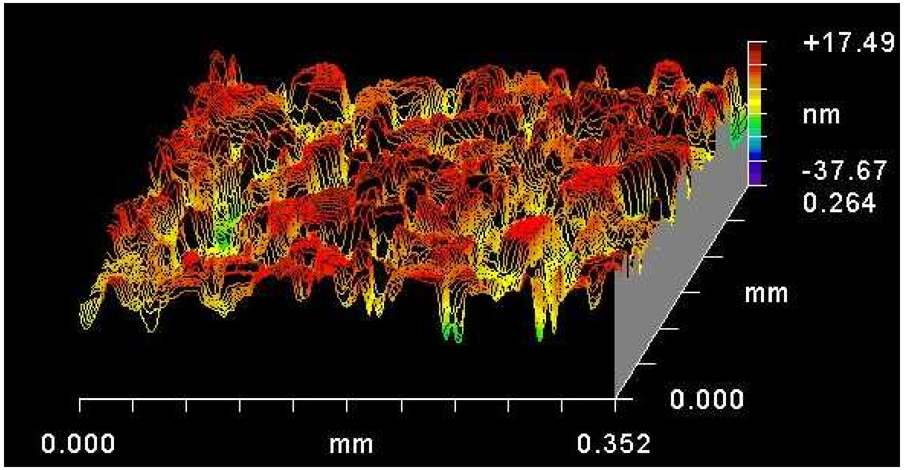
Si wafer cut in
5 ×5 mm^2 plates
Thickness from 390 to 50 μm
ρ = 1 kΩ cm → 10 Ω cm
Roughness ~1 nm



Diamond polyCVD 5 ×5 mm^2 plates
from DDL ltd
Thickness from 500 to 50 μm
Roughness **5 nm at best**
Some scCVD plates recently available



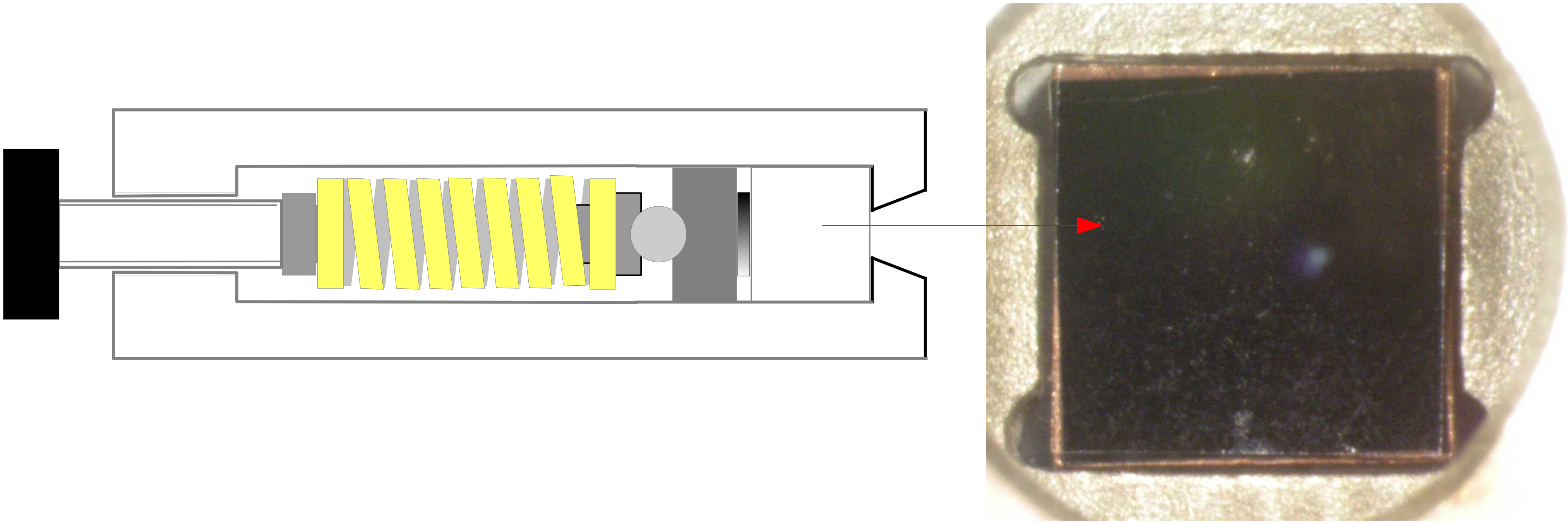
bad aspect ratio on the nucleation side for optical grade samples



Silicon On Diamond Fabrication: Cleaning and mounting

Si & D plates are cleaned in a white chamber in ultrasonic bath
assembled in a laminar flow hood

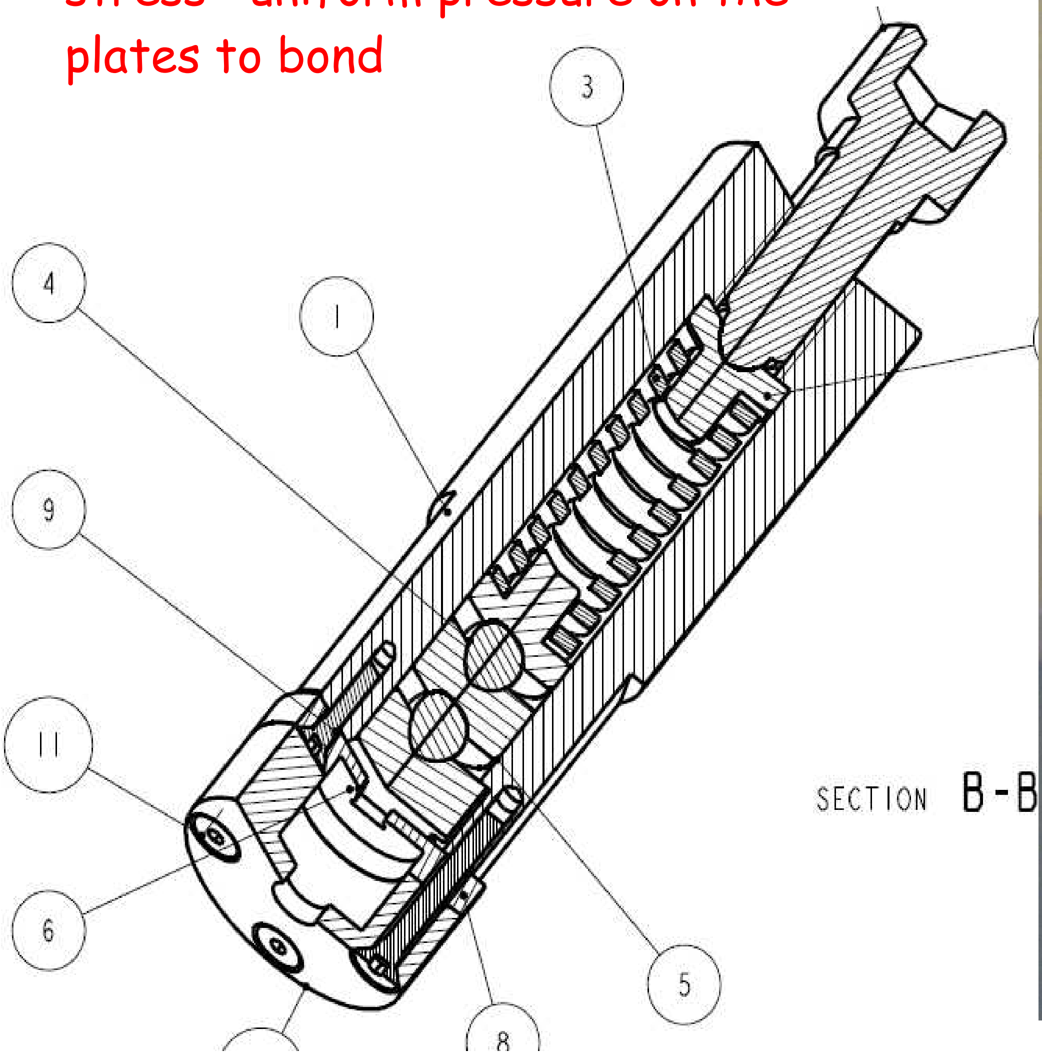
Diamond 5 ×5 mm^2 plate over silicon
seen through the fused silica viewport



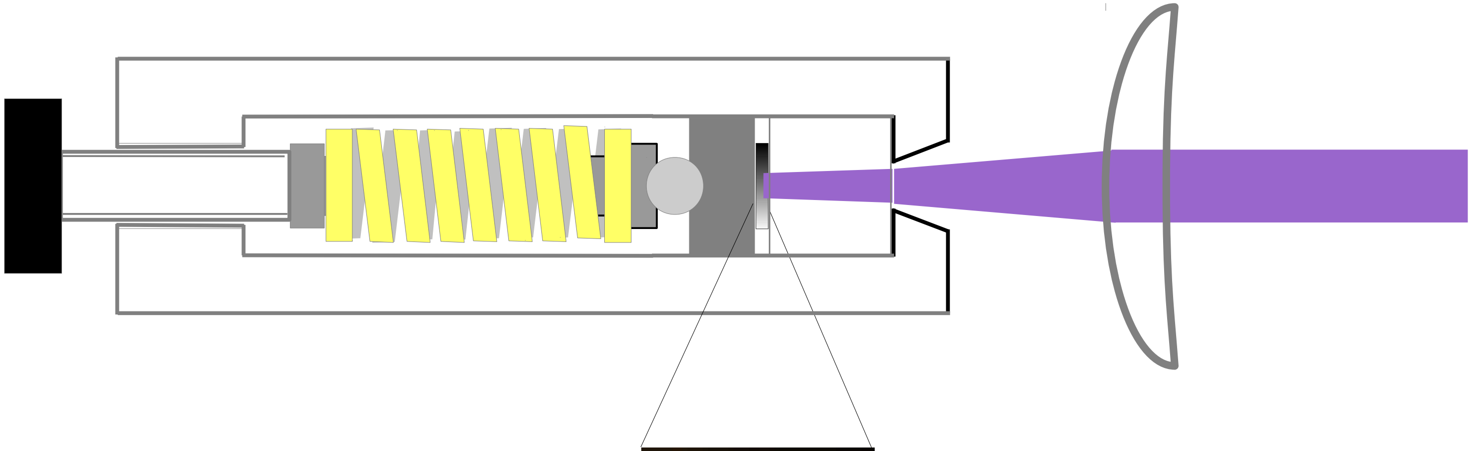
ASSEMBLY IMPLEMENTED BY IIT
(3rd version just released)

Ease to manipulate and assemble pieces

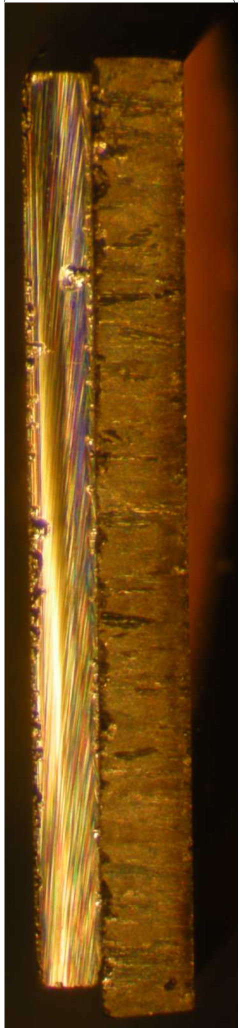
Particular care in ensuring uniaxial stress—uniform pressure on the plates to bond



Silicon On Diamond Fabrication: Laser bonding



Uniaxial stress: 800 atm needed* for 90 % adhesion with the present R_a~5 nm



The diamond silicon interface is irradiated by UV laser pulses

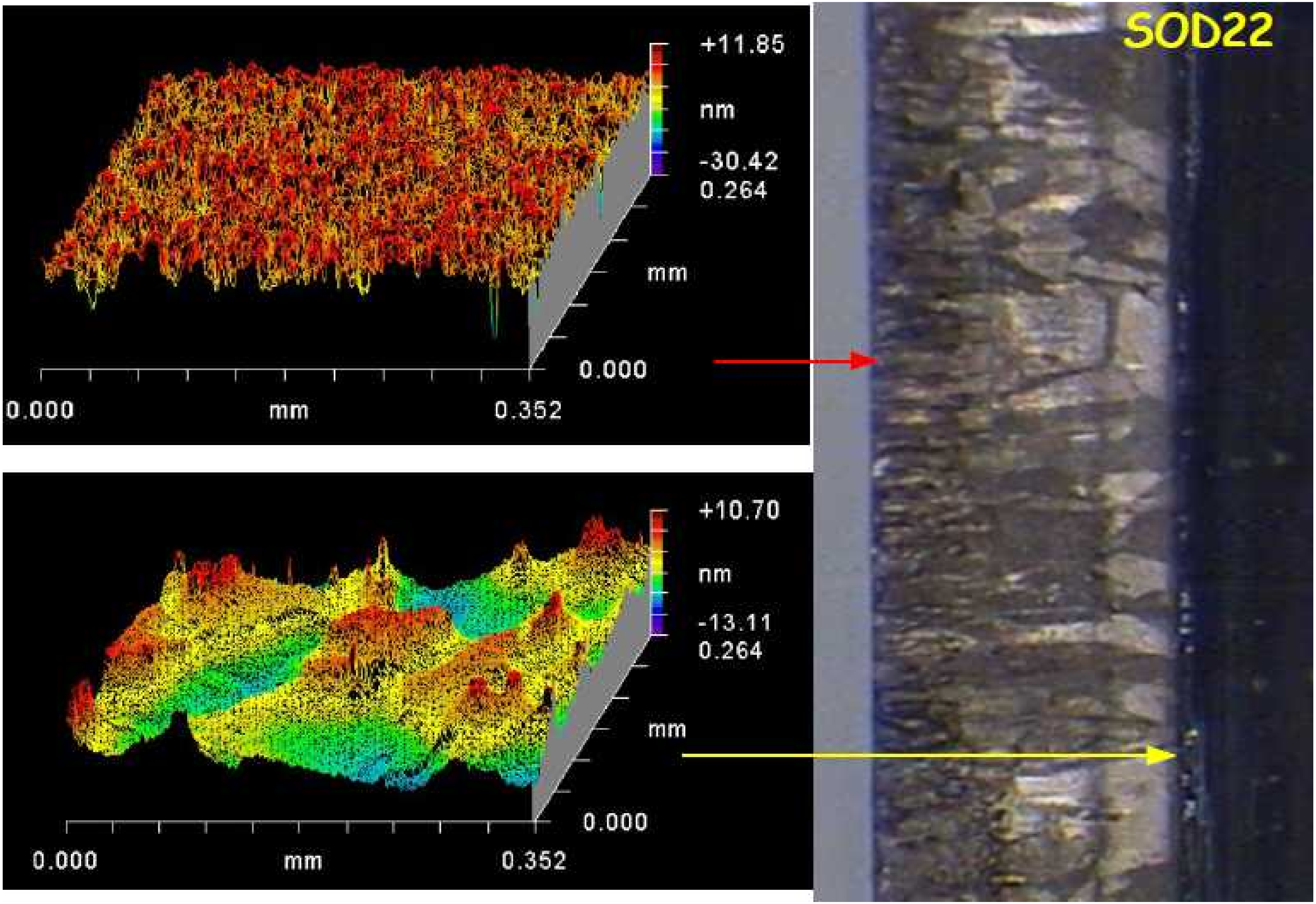
λ=355 nm

τ=20 ps

Energy density = 2-0.5 J/cm^2

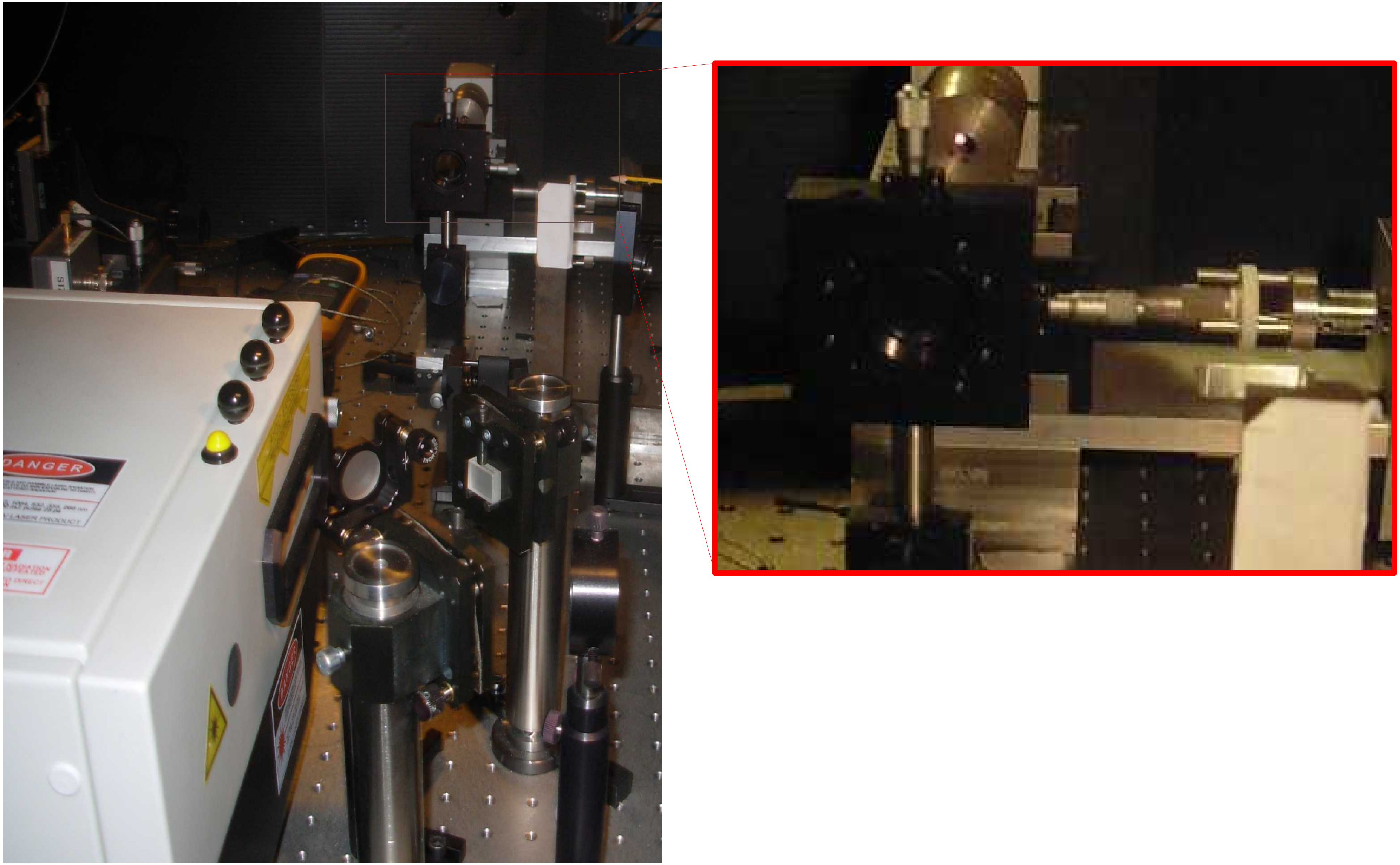
*Stefano Lagomarsino Ph,D Thesis http://hep.fi.infn.it/sciortino/Research/dissertation_Lagomarsino.pdf

Growth side of diamond mounted in contact with the silicon surface



Silicon On Diamond Fabrication: Laser bonding

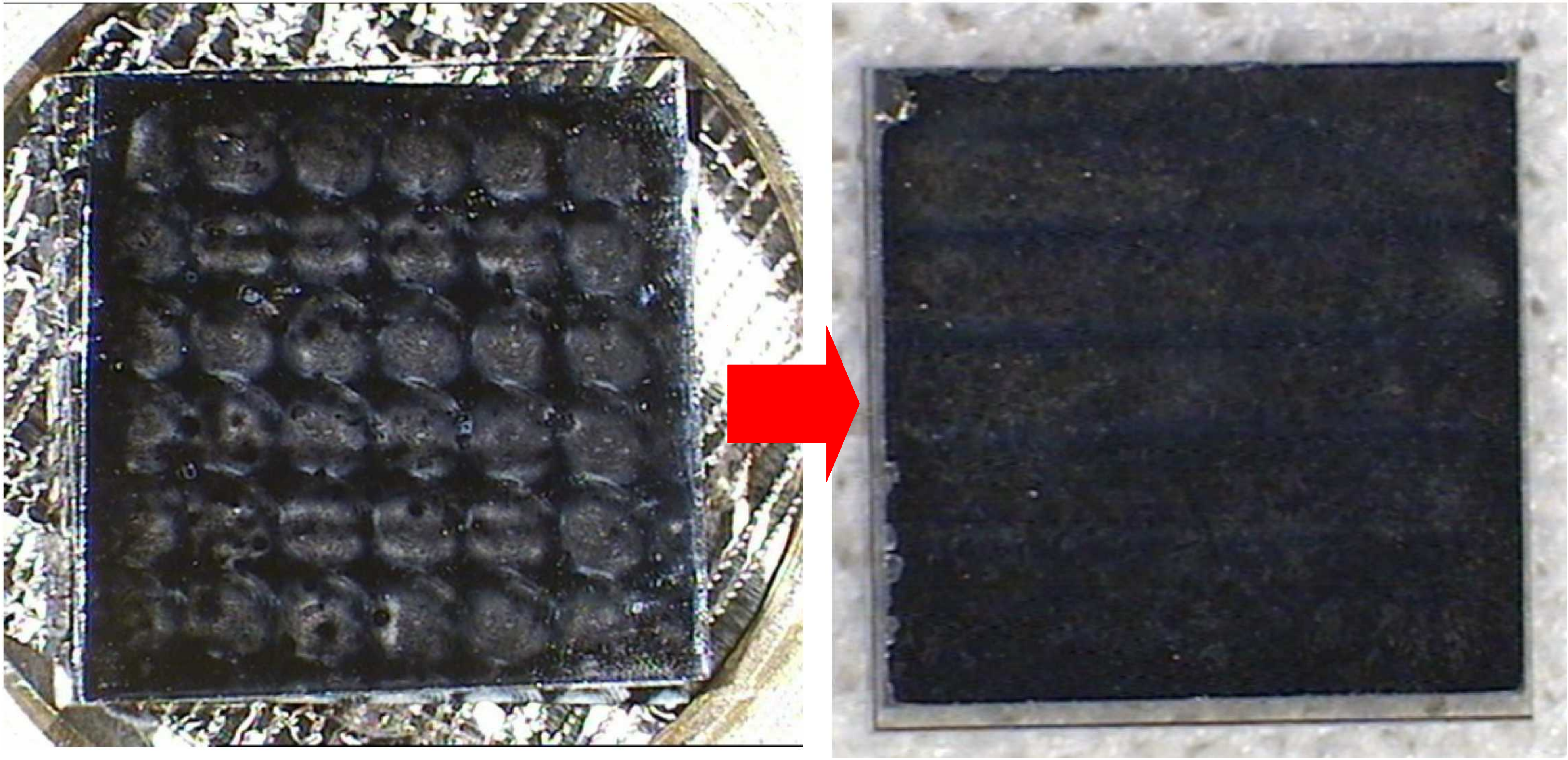
- Automated continuous scanning of the laser beam



Silicon On Diamond Fabrication: scanning the laser beam on the interface

- More uniform illumination of the sample with continuous scanning

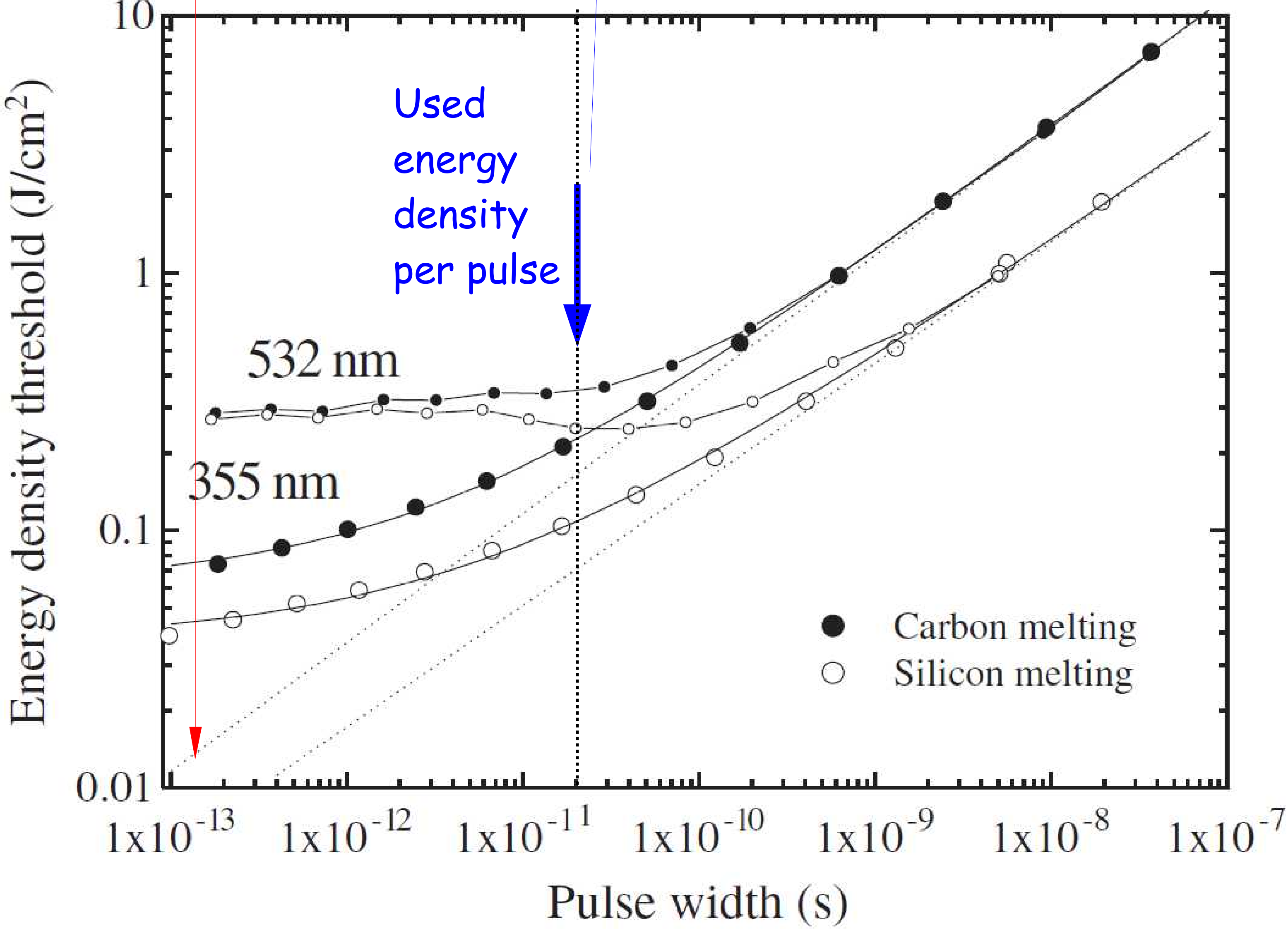
Spot on target 0.9 mm
16 shots per mm on a row
Row separated by 0.7 mm
Energy density 0.5 J/cm^2



SOD12 OCTOBER 2009 & SOD23 JUNE 2011

We can decrease energy density/pulse to threshold at 20 ps about 0.22 J/cm^2, expected interface thickness 40 nm

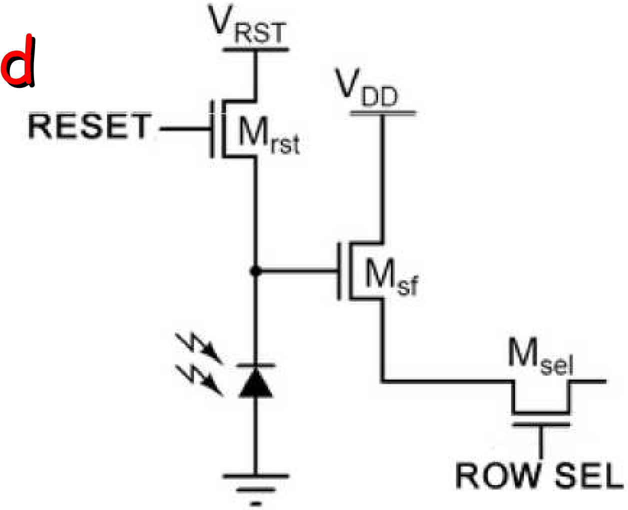
Or even lower the pulse width to lower the interface thickness to about 10 nm



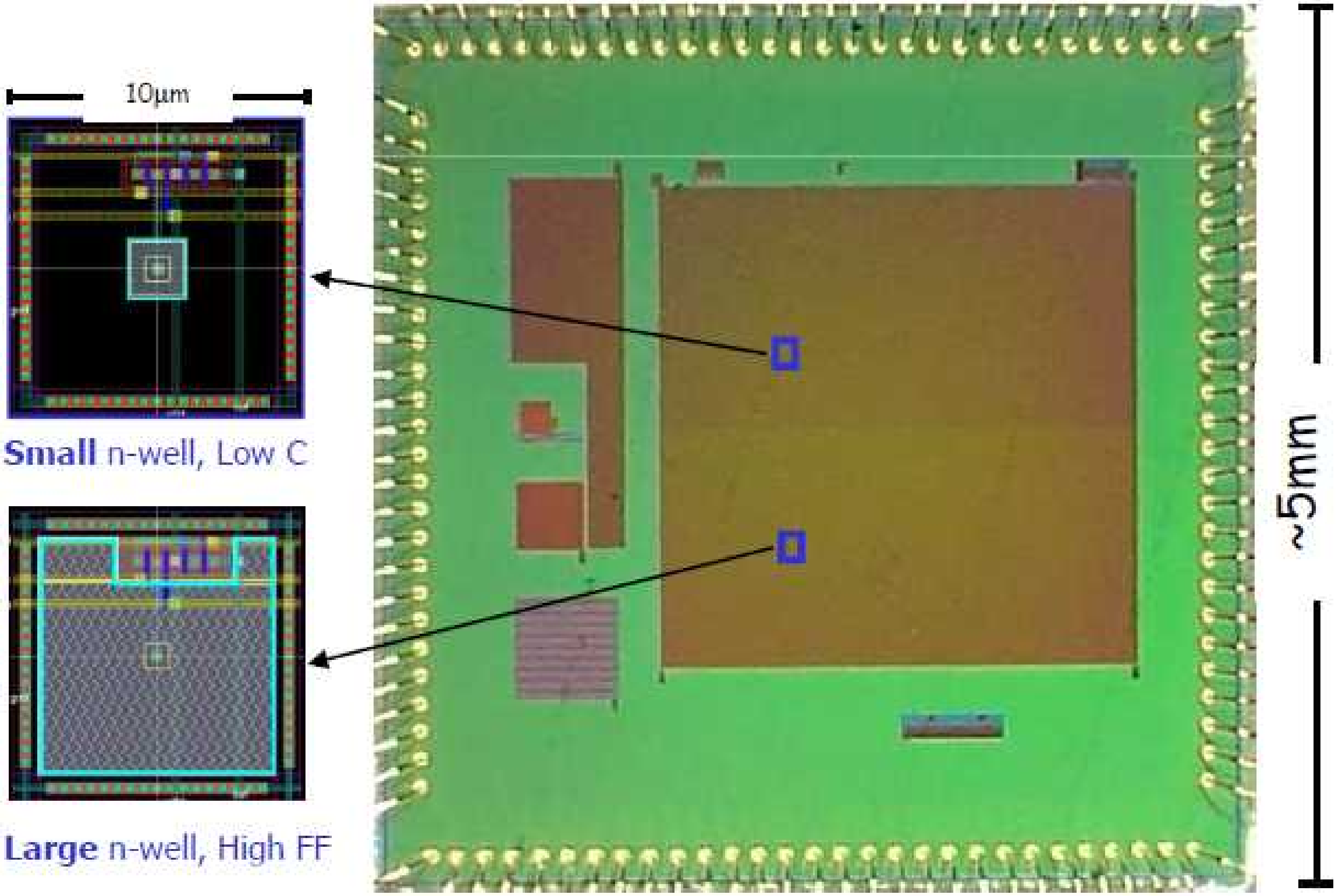
Used energy density per pulse

S. Lagomarsino, Diamond & Related Materials 20 (2011) 1010–1015

RAPS on DIAMOND: succesfully tested

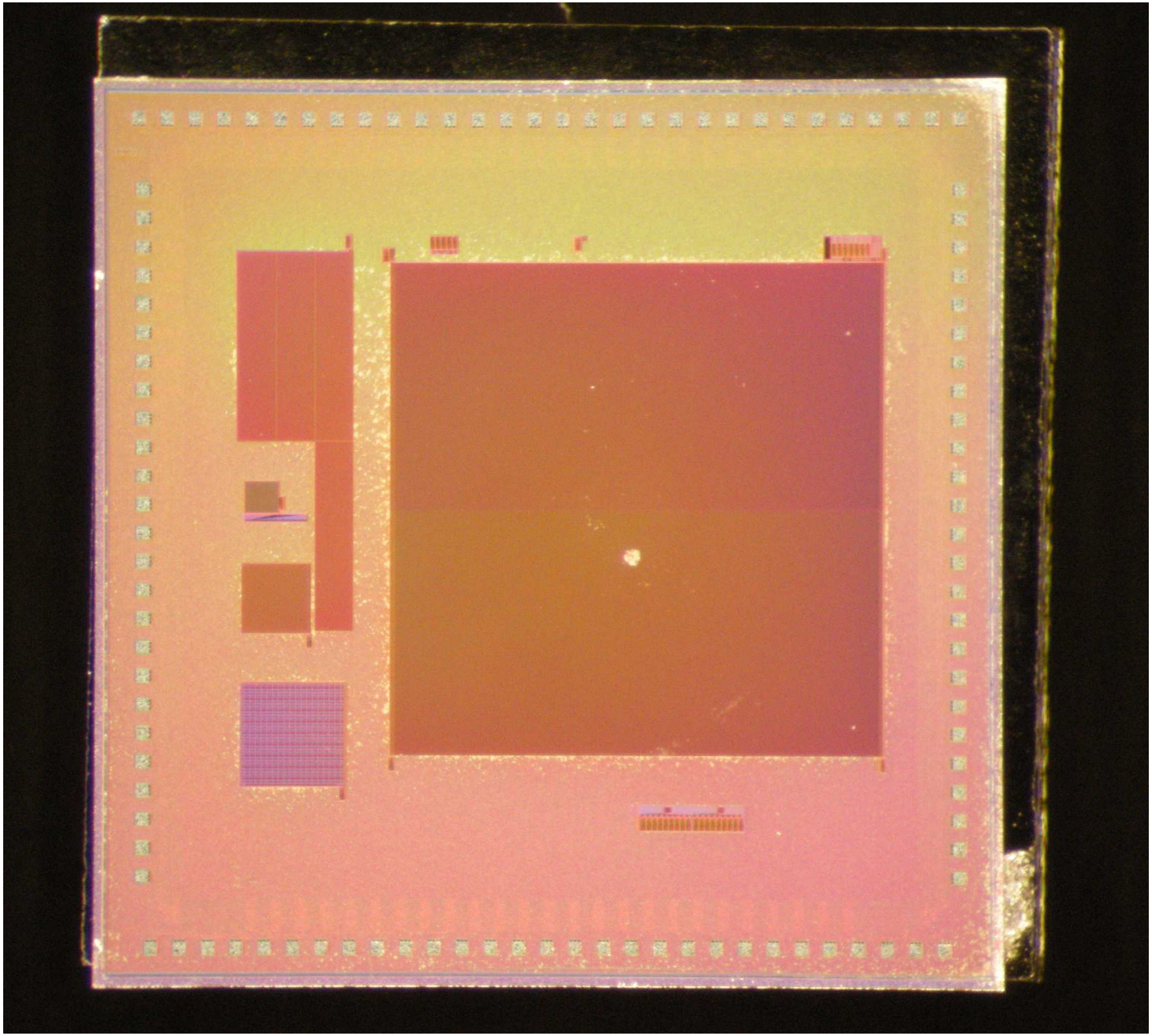


GOAL:
To test the functionality of a real chip
After ⇒ thinning (down to 40 µm)
and⇒ bonding to diamond

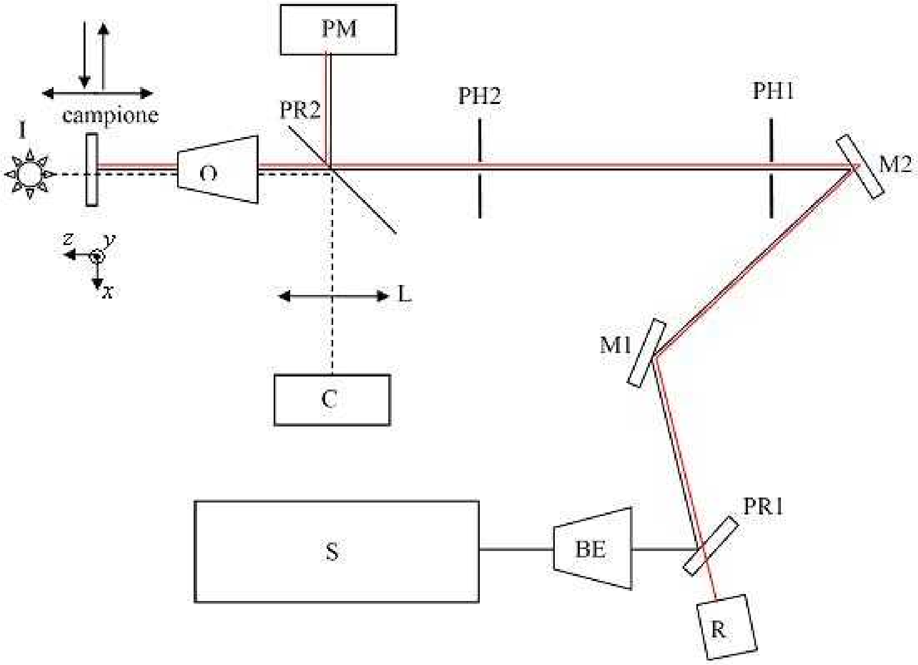


CMOS Active Pixel Sensors
256 × 256 matrix

RAPS bonded on diamond (SOD_34) successfully tested



LASER graphitization: sources



Nd:YAG Q-switched laser source

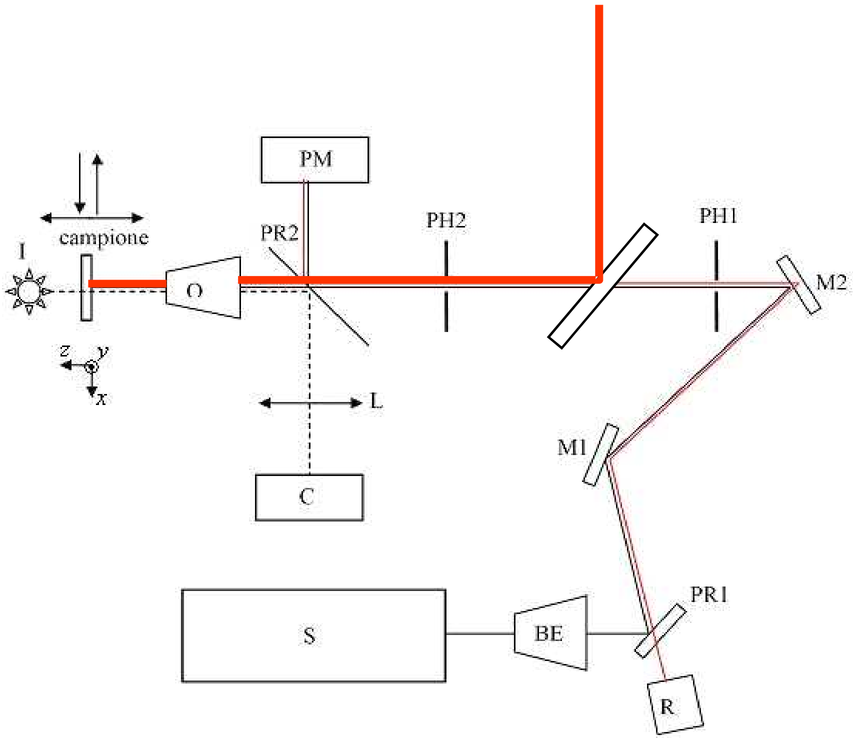
1064 nm wavelength

8 ns pulse width

<100 μJ per pulse

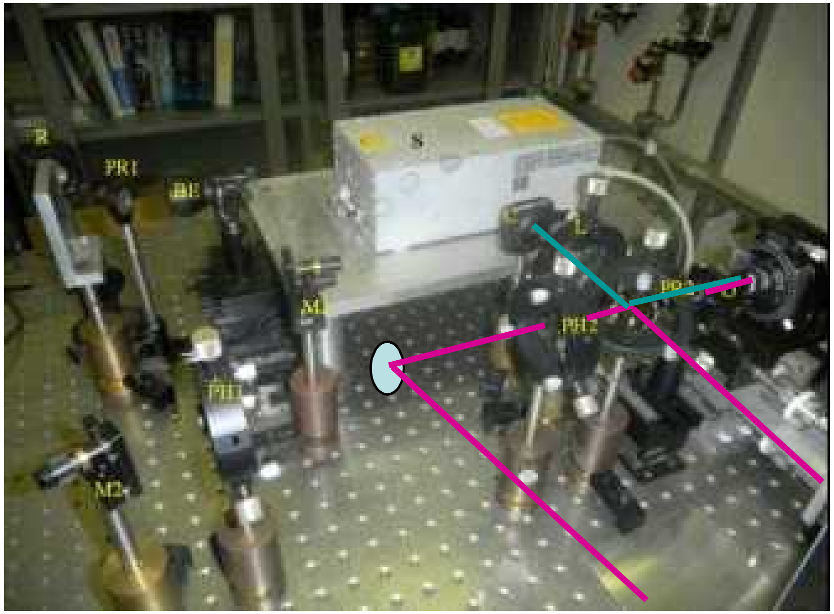
Realtime visualization system : 1 μm resolution

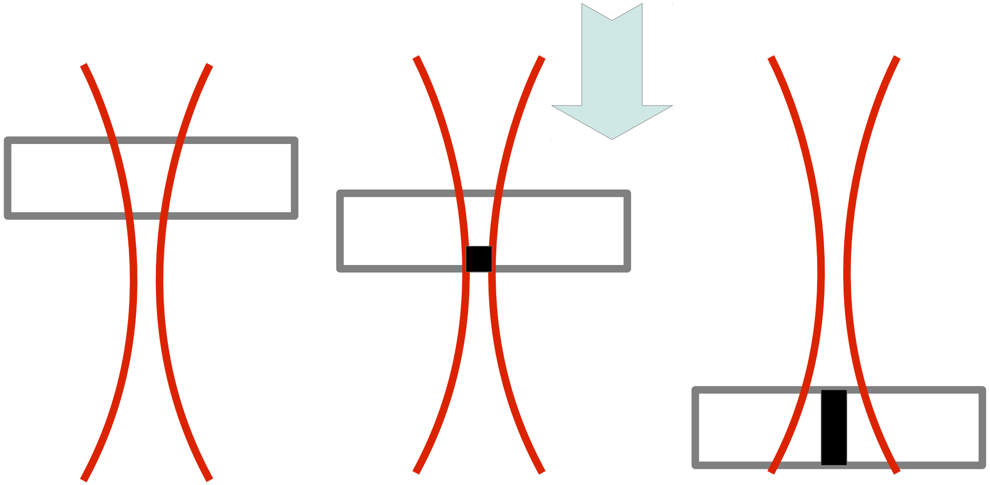
xyz automated stages



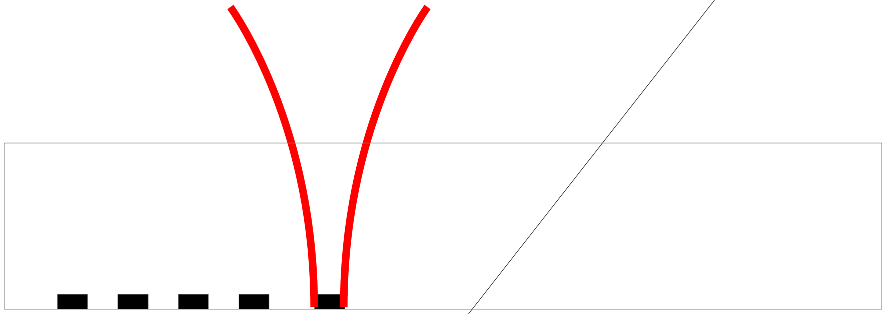
Inserted a line for a Ti:Sa 800 nm, 30 fs laser beam <3 J/pulse

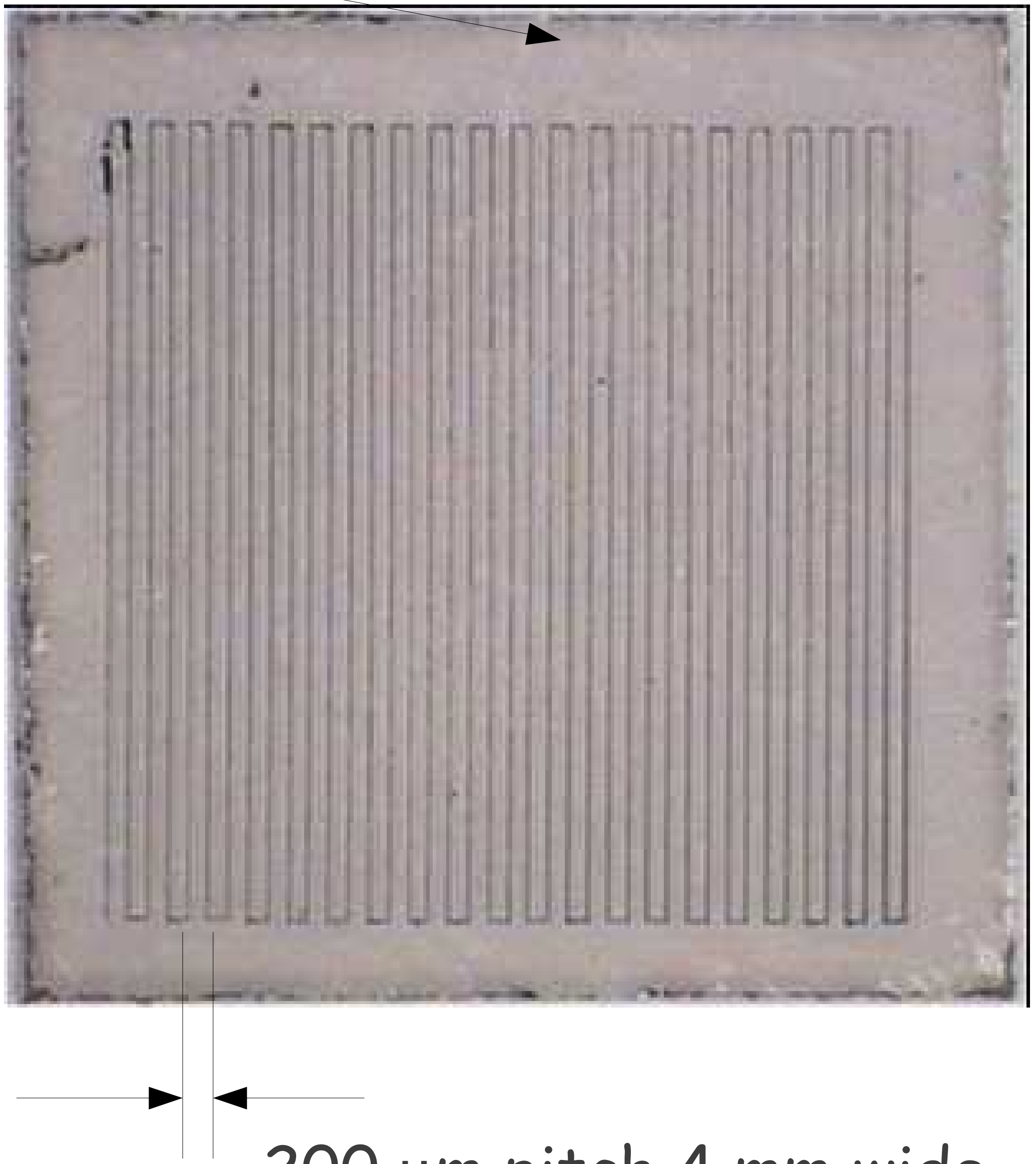
Channels bulk fabrication
Sample is moved across the focus and columnar growth occurs above a threshold energy





Graphitic superficial dots or stripes can also be fabricated



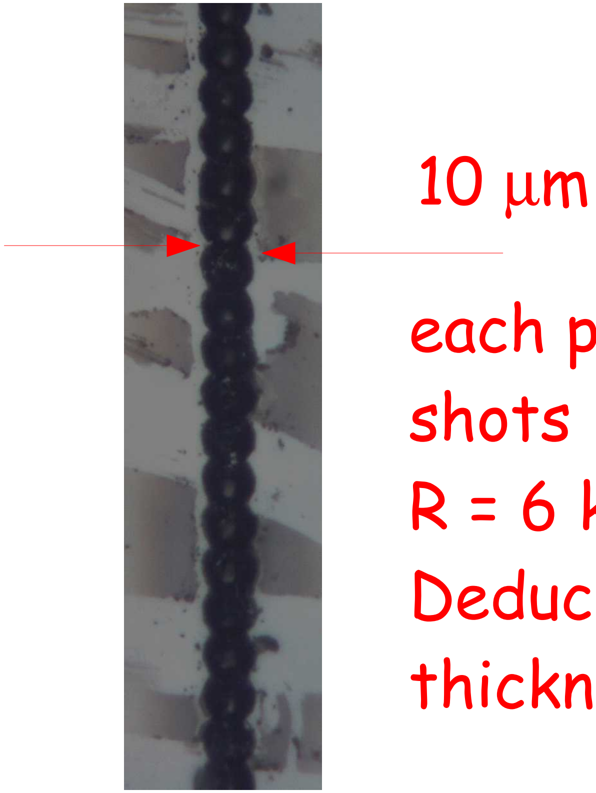


200 μm pitch 4 mm wide serpentine (ns laser)

The superficial channels are graphitic as assessed by Raman spectroscopy

$$\rho = 4.5\,\mathrm{m}\Omega\ \mathrm{cm}$$

in agreement with the amorphous graphite value

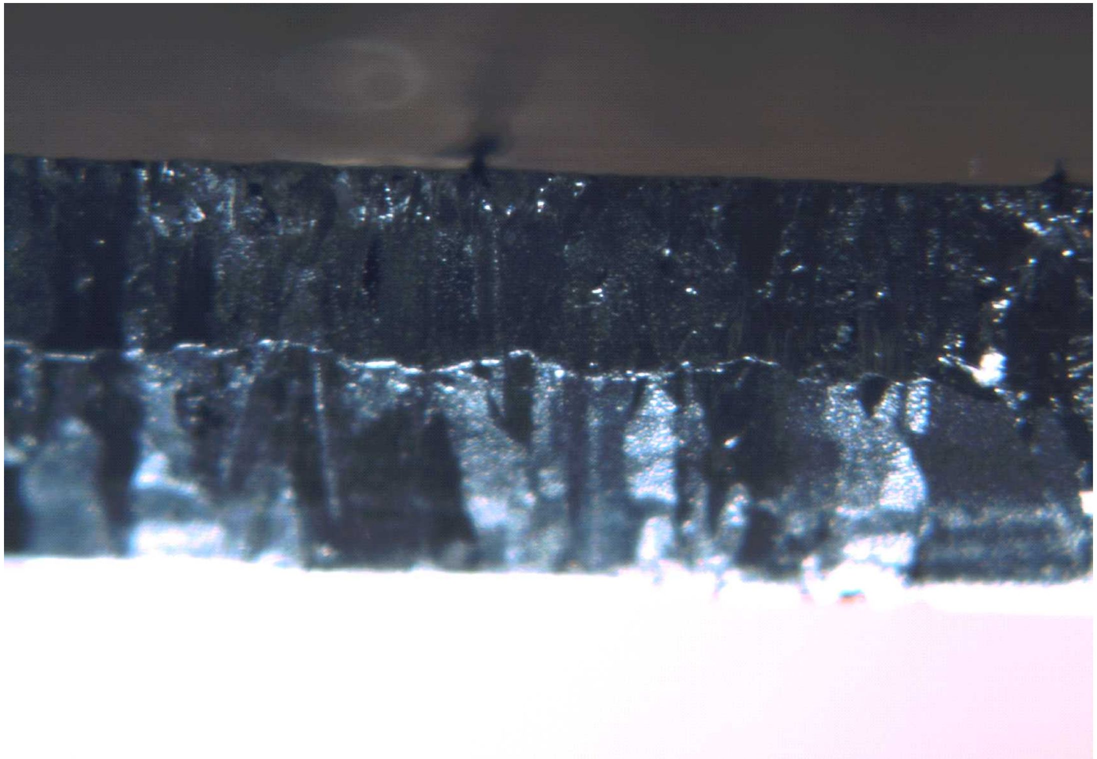


each point: 10 shots

R = 6 kΩ/mm

Deduced thickness ~ 1 µm

We can modulate thickness (and hence resistance) varying the number of shots per point.



Nanosecond columns through diamond bulk

9 μJ/pulse

1.5 -5.5 μm diameter

Higher resistivity

$$\rho = 0.3 - 0.4\Omega \text{ cm}$$

Only traces of graphite signature by graphite spectroscopy

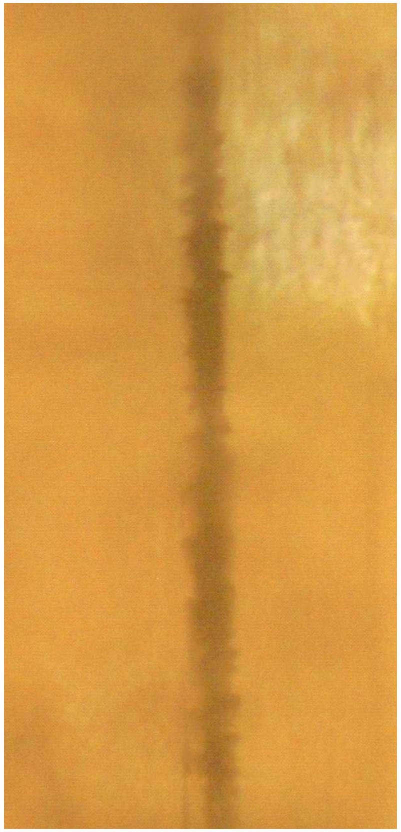
High pressure gradient formed, up to 10 GPa

Fractures, non-uniformity

Femtosecond columns through diamond bulk

1.5 μJ/pulse

8-10 μm
diameter



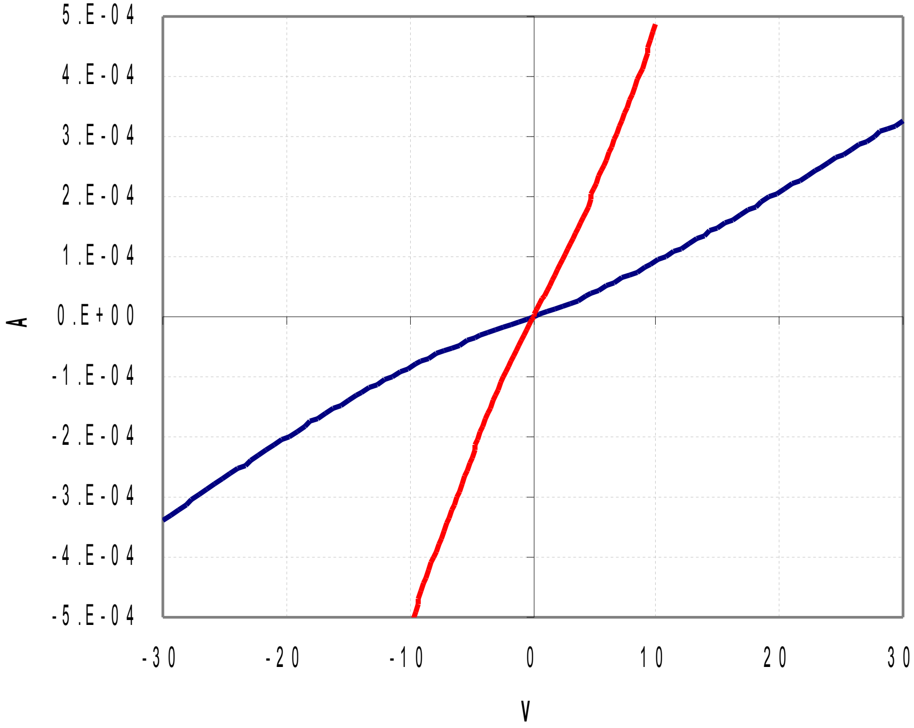
Even higher
resistivity

$$\rho = 1.3\ \Omega\ \mathrm{cm}$$

No damage to
the diamond
lattice!

Low residual
stress!

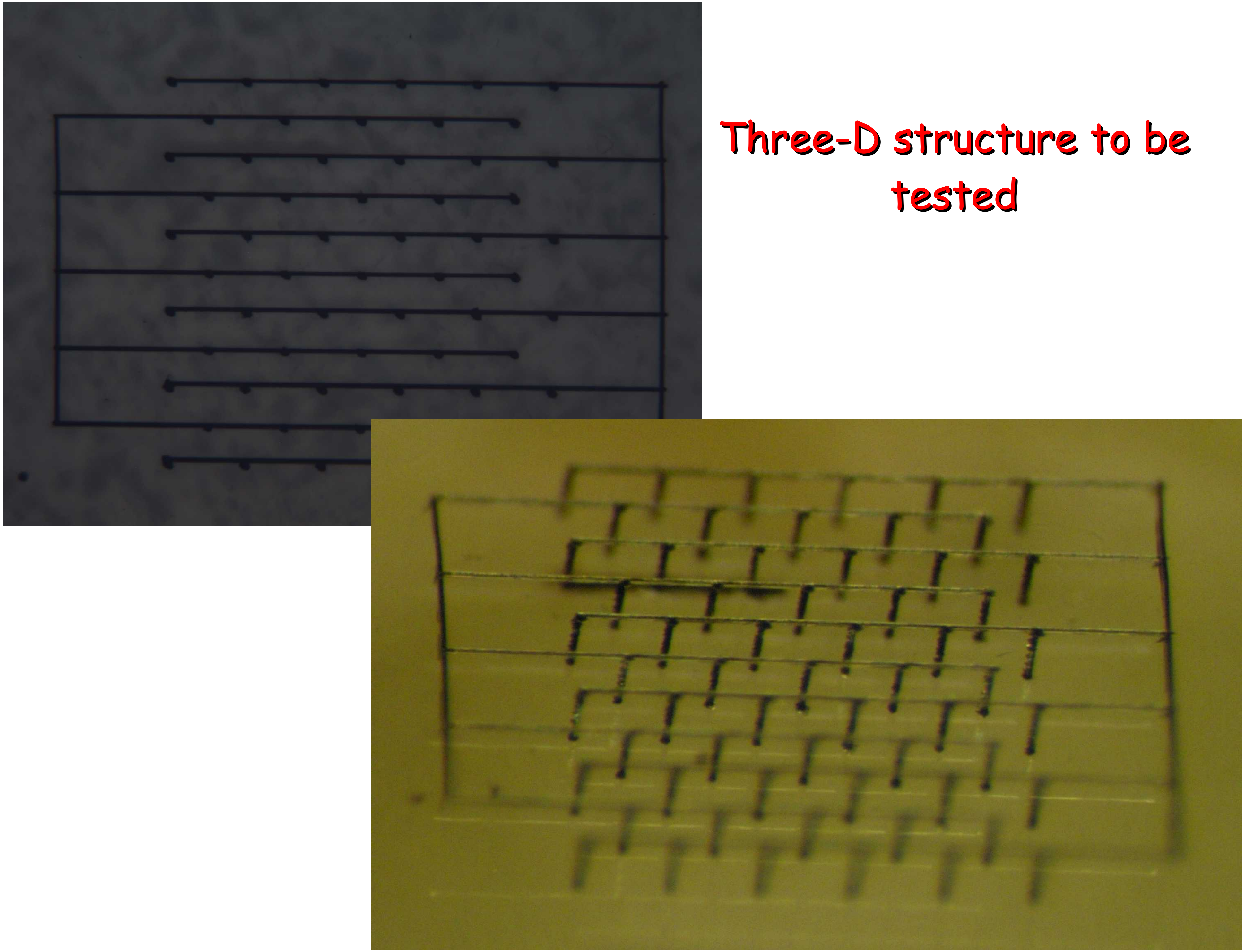
Annealing of the bulk nanosecond channels



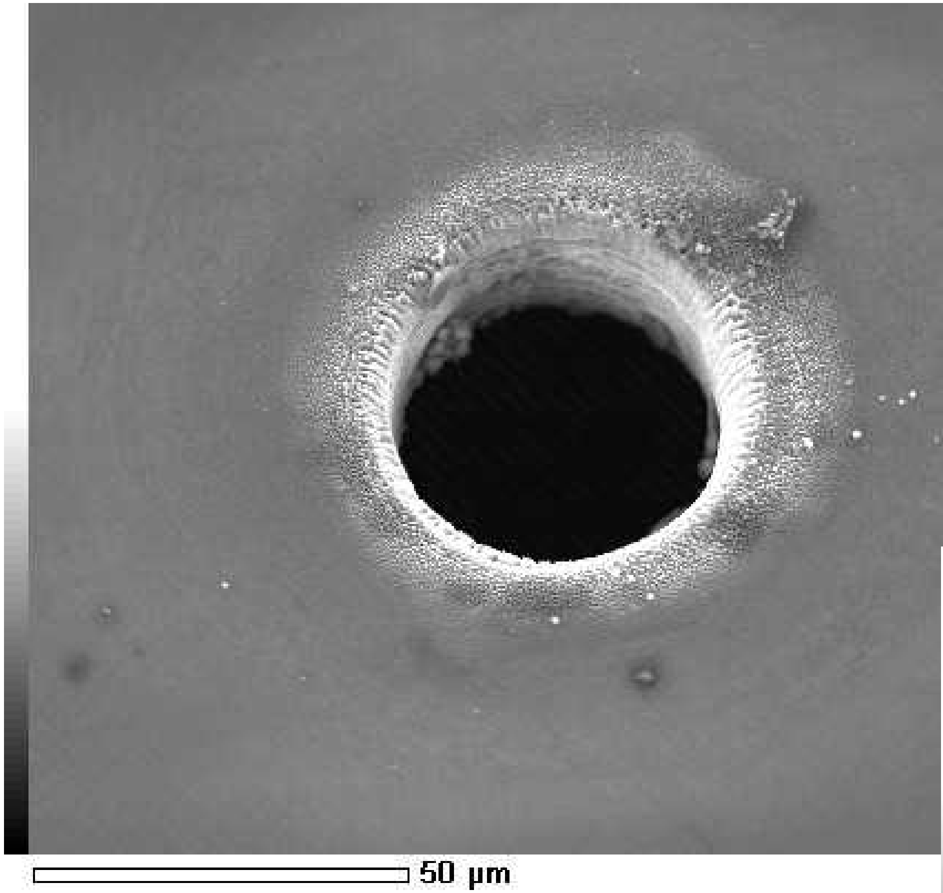
After annealing at 1000 K for 1h under Ar atmosphere , resistance of ns pulses-fabricated columns decrease of a factor 5

We have to assess possible modifications in the raman spectra

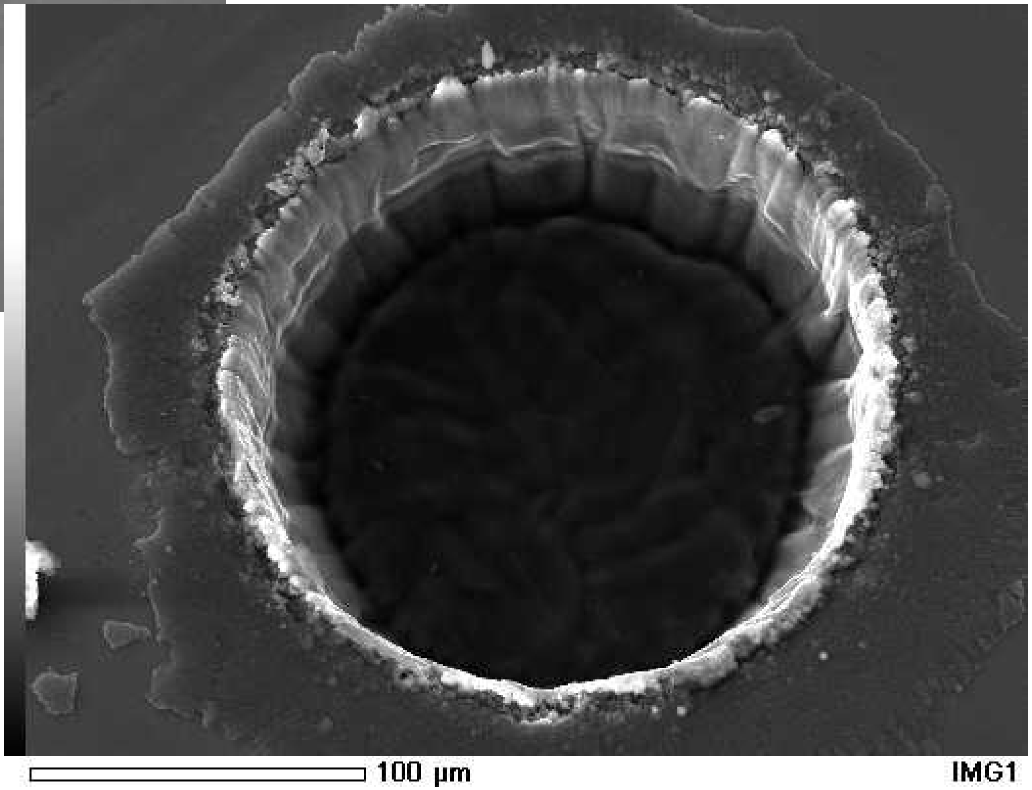
We have to anneal also fs pulses-fabricated columns



Three-D structure to be tested

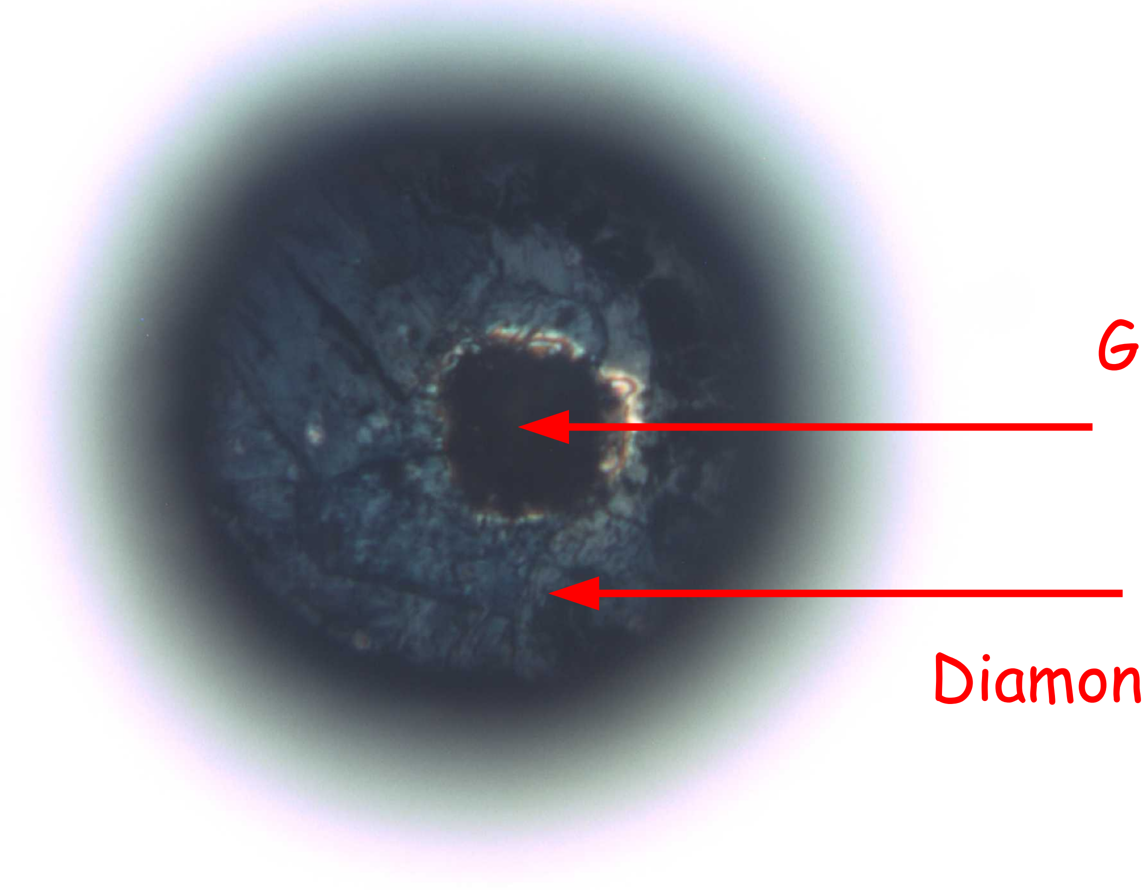


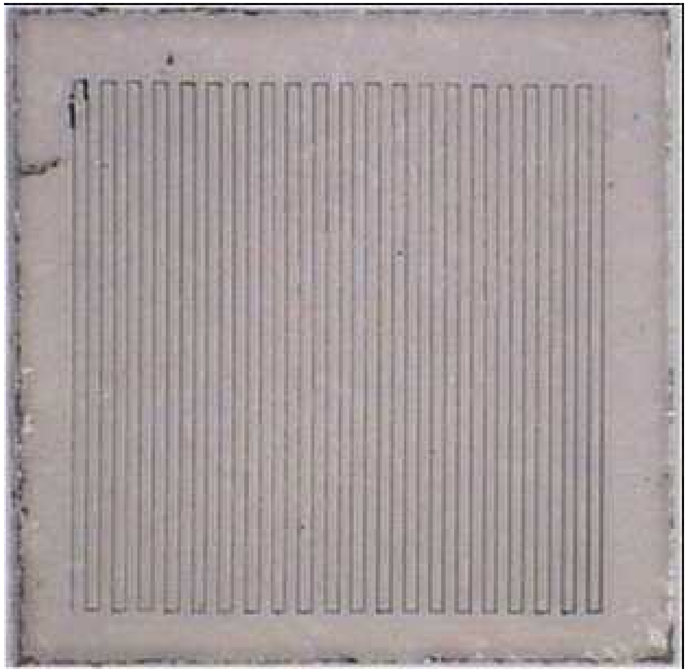
Through Silicon Vias drilled
in the silicon by excimer
laser
(Si typical thickness 50 µm)

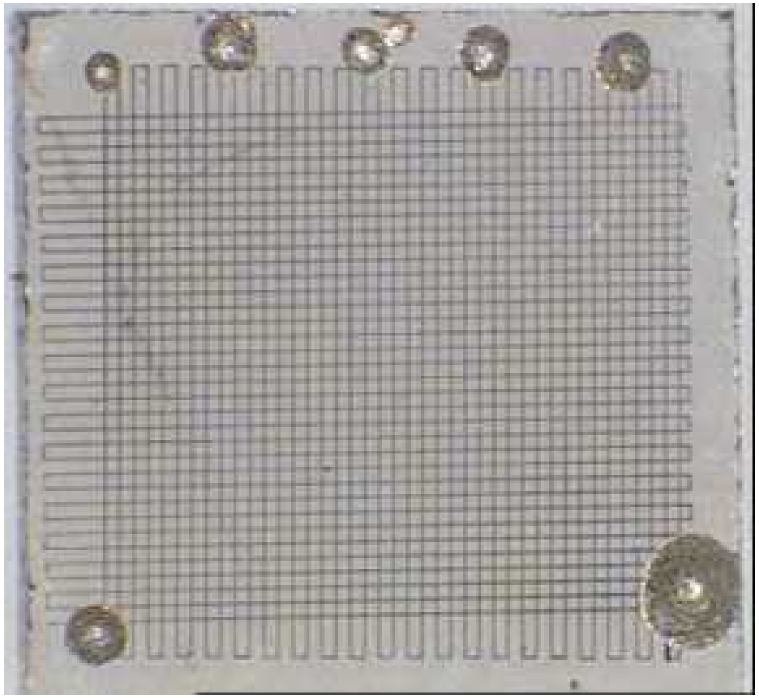


TSV and graphitic channels are presently fabricated on the SOD samples

Looking into a TSV



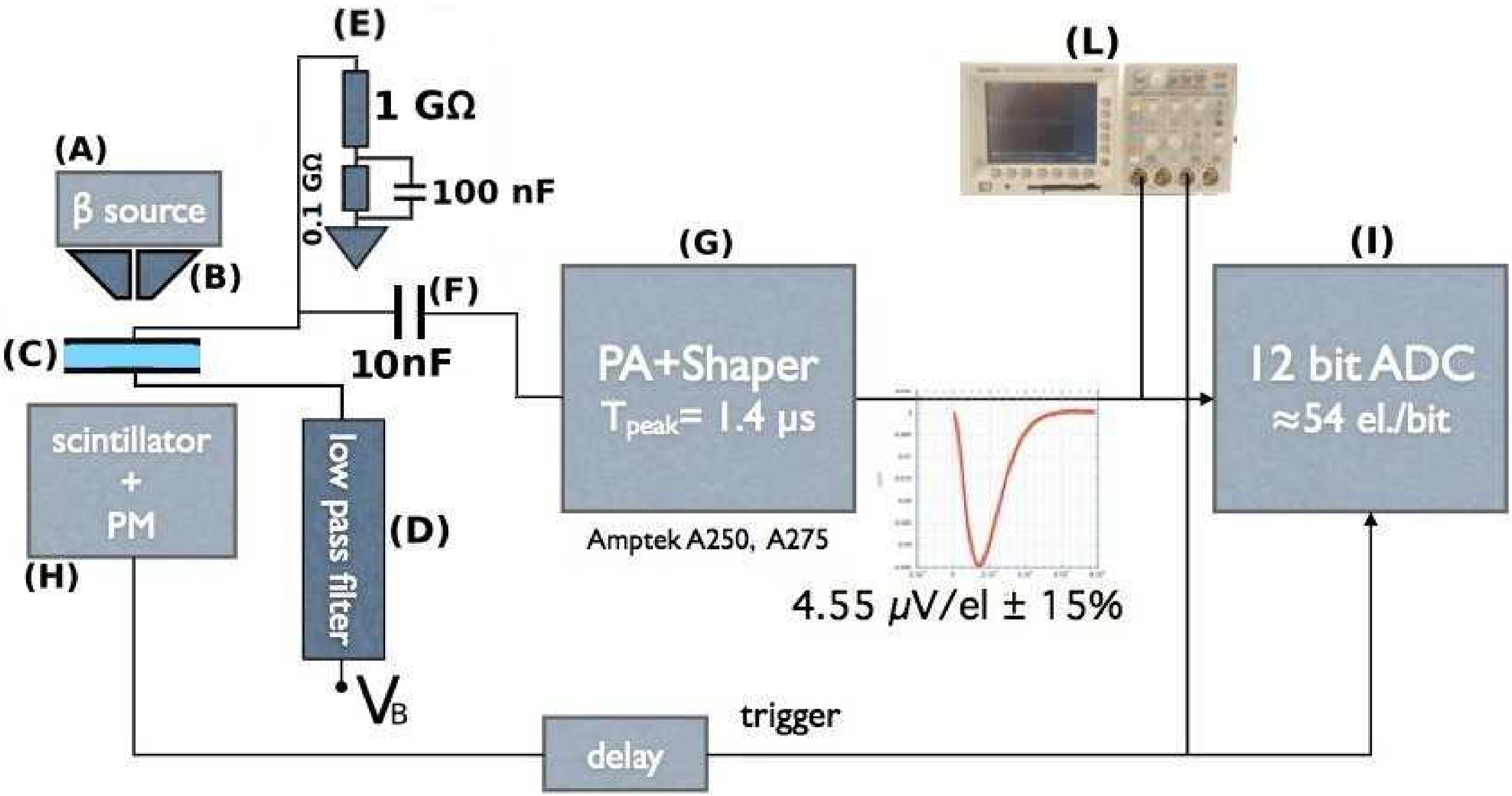




Diamond detector with graphite contacts

Detector Characterization
Charge Collection Efficiency Measurement

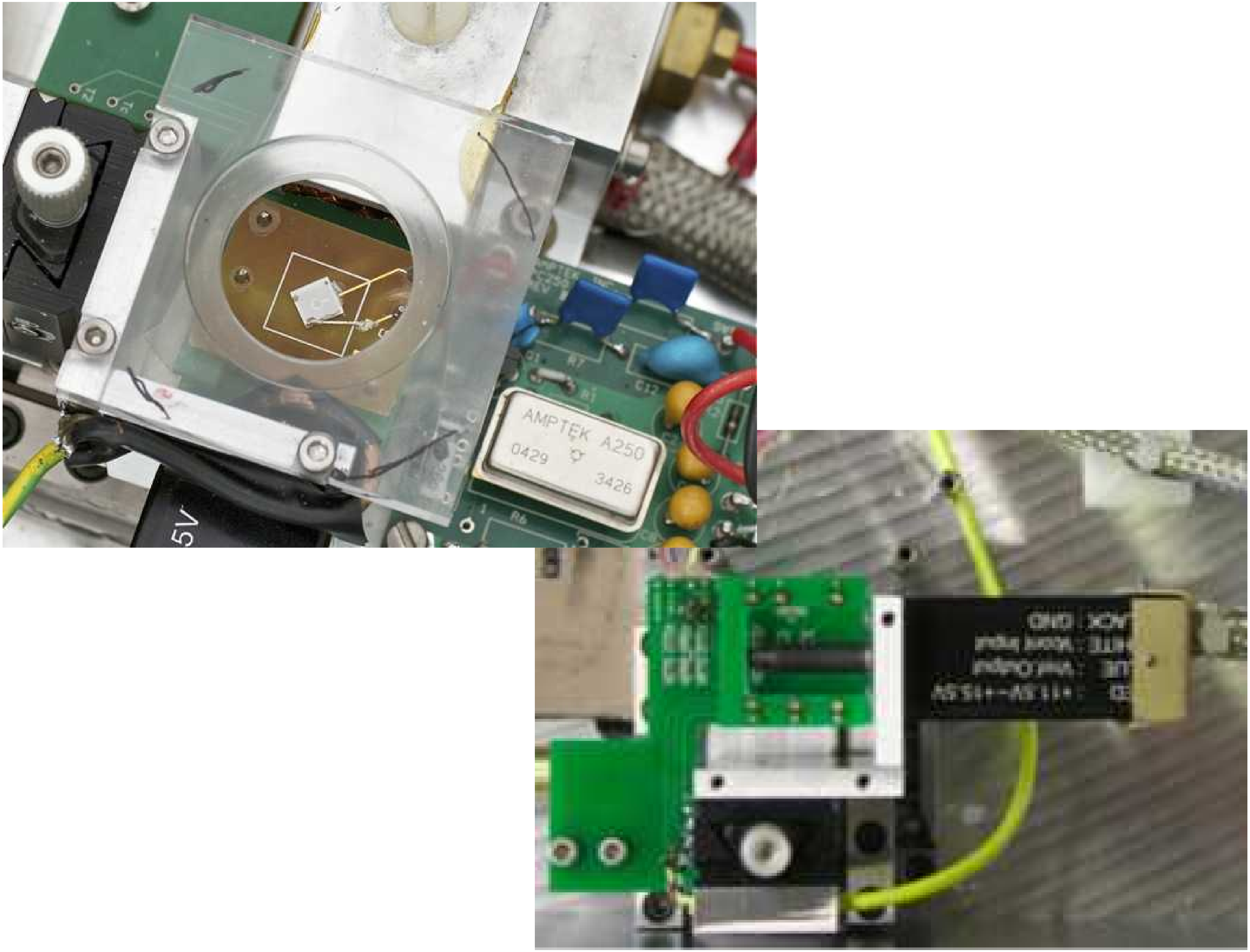
(A) beta source (B) collimator (C) DUT (D) power supply (E) GW load resistor)



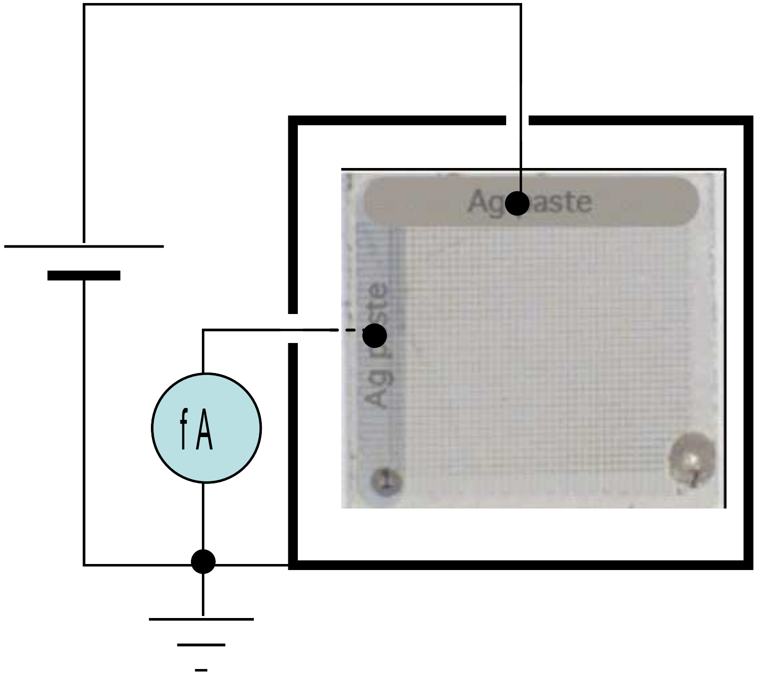
(F) decoupling C (G) Amptek shaper (H) Trigger (I) PCI NI ADC Board (L) Scope


PC-275
AMPTEK
RED : +11.5V~+15.5V
BLUE : Vref.Output
WHITE : Vcont Input
BLACK : GND

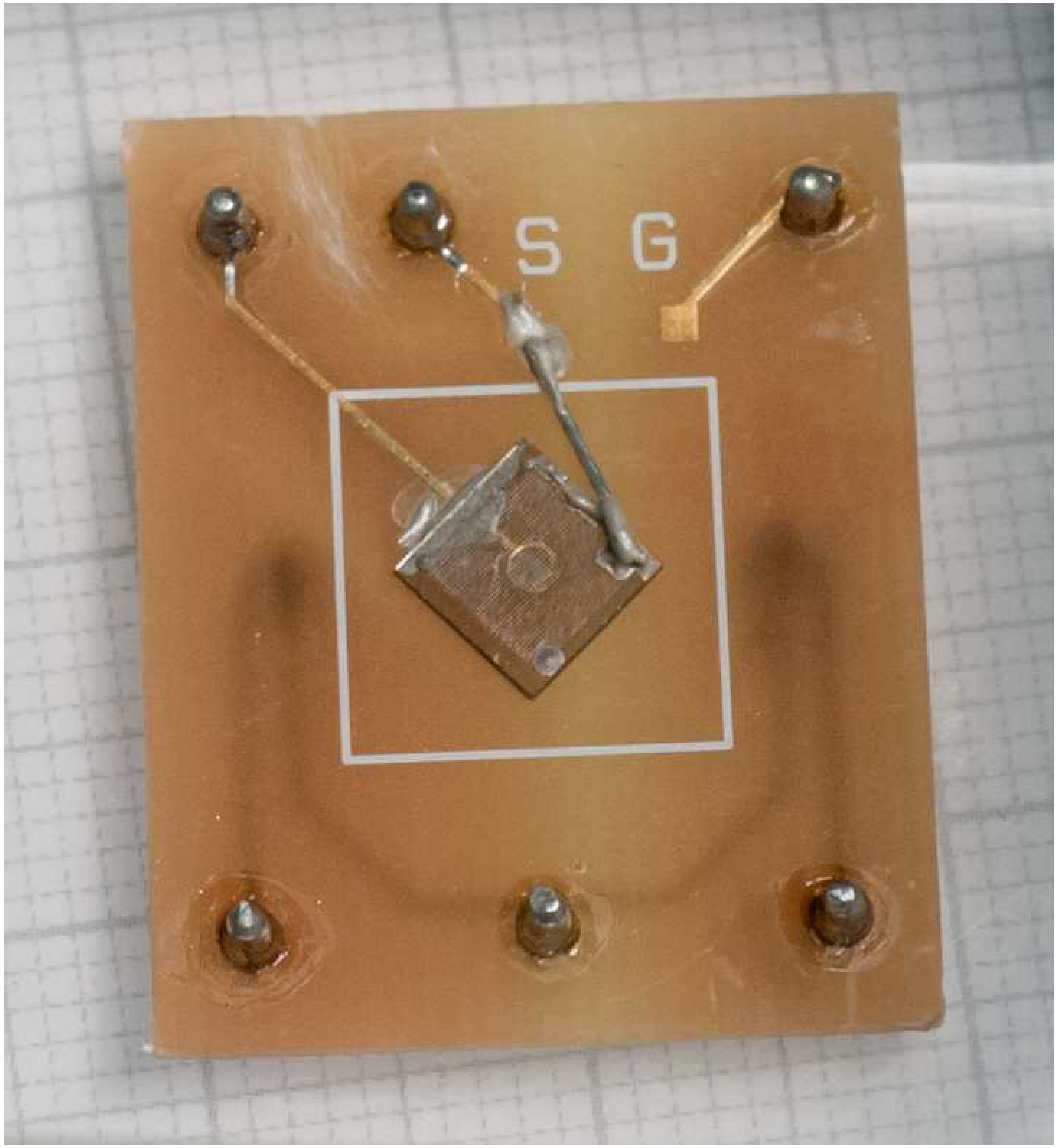

RED : +11.5V~+15.5V
BLUE : Vref.Output
WHITE : Vcont Input
BLACK : GND
PC-275
AMPTEK


AMPTEK A250
0429
3426
R7
R1
R6
C12
5V

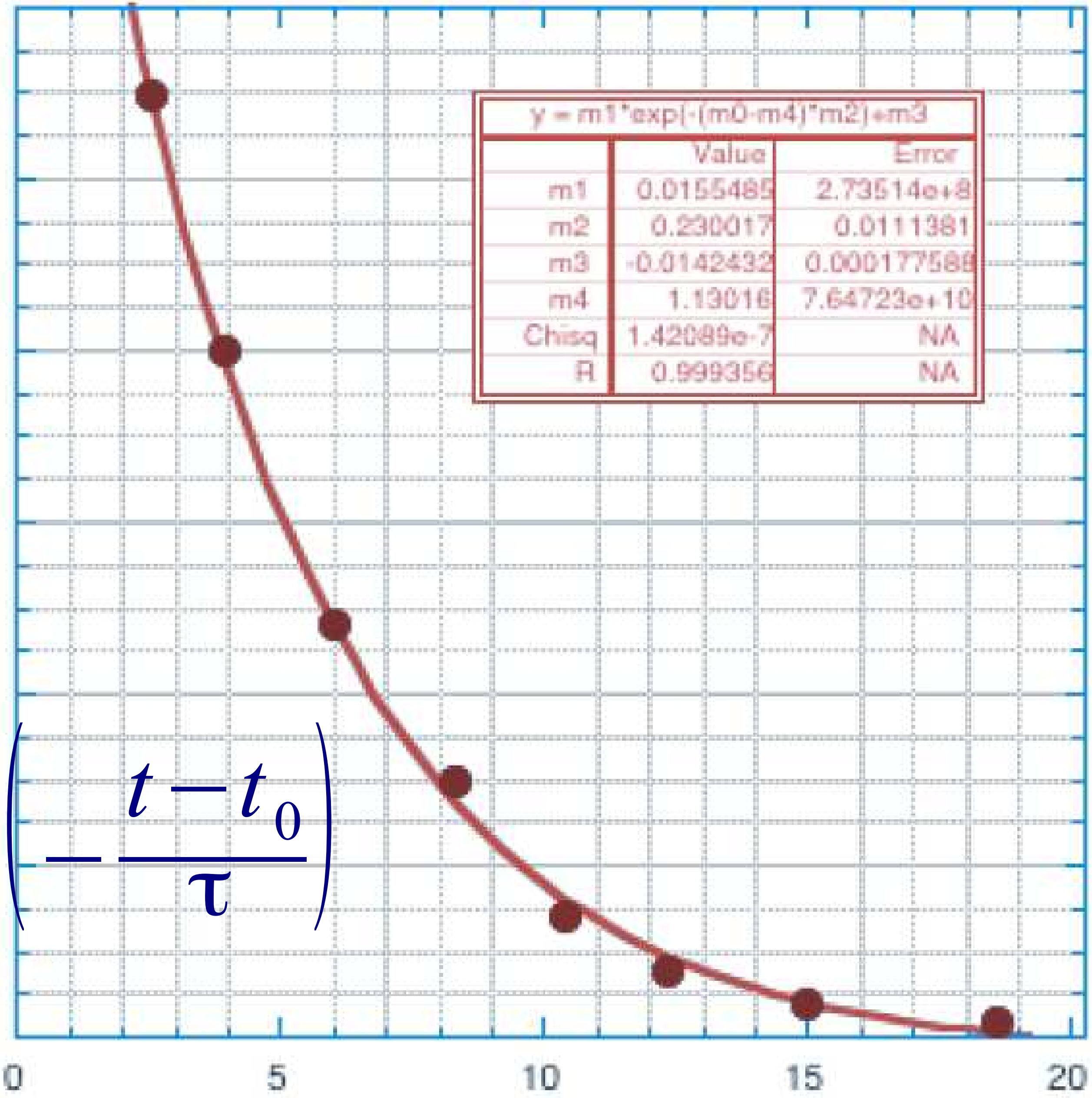
$$C = 2.4\ \text{pF}$$



$$R \sim 10^{15}\ \Omega$$



Relaxation of the zero bias signal due to polarization



y = m1*exp(-(m0-m4)*m2)+m3

	Value	Error
m1	0.0155485	2.73514e+8
m2	0.230017	0.0111381
m3	-0.0142432	0.000177588
m4	1.13016	7.64723e+10
Chisq	1.42089e-7	NA
R	0.999356	NA

$$Q_{\mathrm{av}} = A + B \exp\left(-\frac{t - t_0}{\tau}\right)$$

Charge Collection Efficiency vs. Mean Free Path

Mean Free Path (for each carrier)

$$\lambda = v\,\tau$$

Drift Velocity

$$v = \frac{\mu E}{1 + \mu E / v_{\mathrm{sat}}}$$

For an homogeneous, i. e., single crystal diamond

$$\frac{Q_{av}}{Q_{gen}} = \frac{\lambda}{L}\left[1 - \frac{\lambda}{L}\left(1 - e^{-\frac{L}{\lambda}}\right)\right] = z\left[1 - z\left(1 - e^{-\frac{1}{z}}\right)\right]$$

L is the sample thickness, $z = \frac{\lambda}{L}$

Diamond with MFP linearly increasing with thickness

$$\lambda = a\,x + \lambda_{min}, \qquad a = \frac{\lambda_{max} - \lambda_{min}}{L}$$

$$\frac{Q_{av}}{Q_{gen}} = \frac{1}{\zeta^2}\,\frac{B}{2\cdot B - 1}\left\{\zeta - \frac{1}{2}\zeta^2 B\left[(1+\zeta)^{\frac{1}{B}} - 1\right]\right\}$$

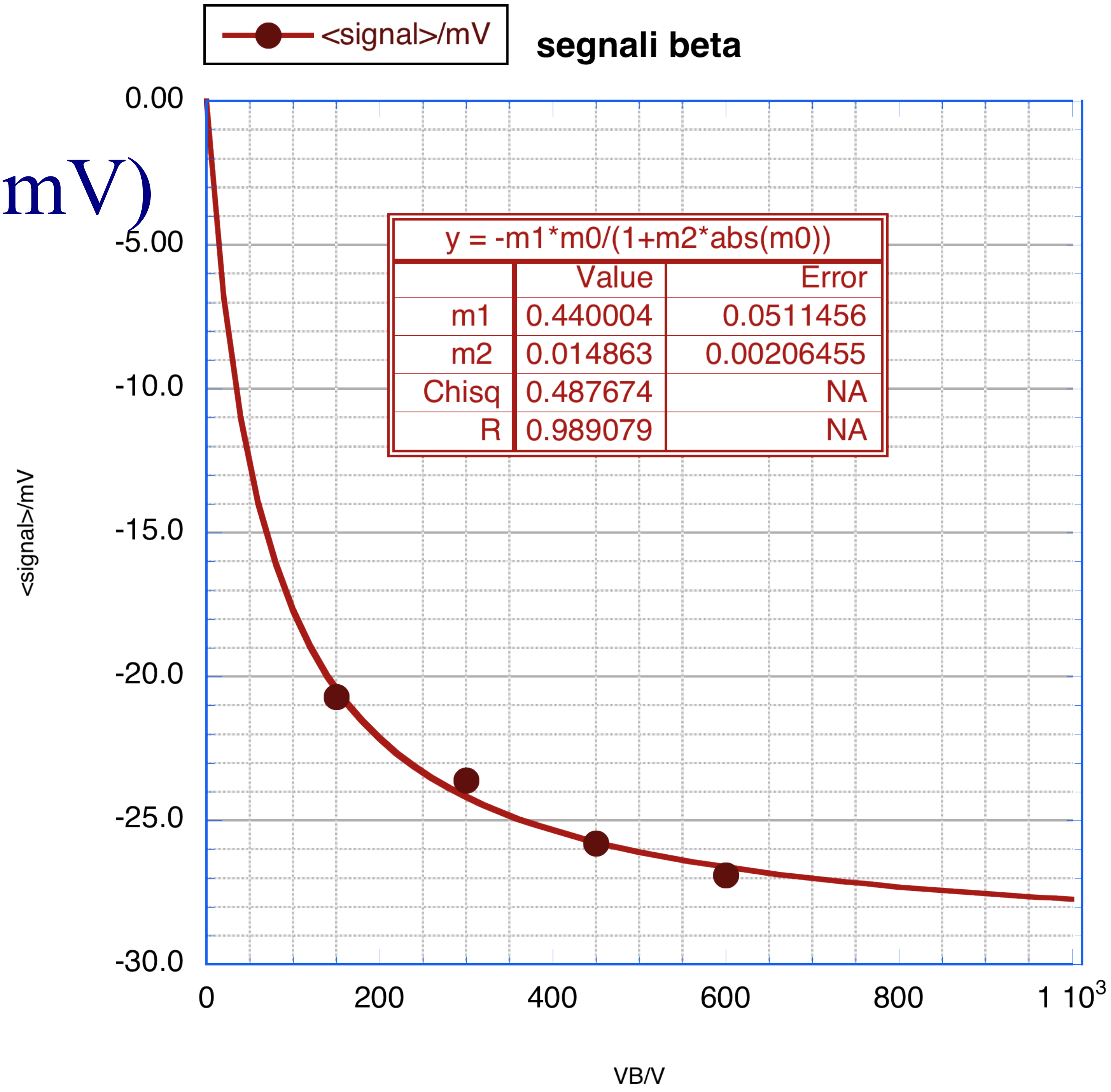
$$\text{with: } z = a\,\frac{L}{\lambda_{max}} = \frac{\lambda_{max} - \lambda_{min}}{\lambda_{max}}, \qquad B = \frac{a}{a-1}$$

Numerical approximation within a percent:

$$\boxed{\frac{Q_{av}}{Q_{gen}} = \frac{1}{2}\,\frac{\dfrac{\lambda_{max}}{L}}{\dfrac{\lambda_{max}}{L} + m\left(\dfrac{\lambda_{min}}{\lambda_{max}}\right)}}$$

$$m = 0.36 - 0.4 \ \text{ for: } \frac{\lambda_{min}}{\lambda_{max}} = 1 - 0.1$$

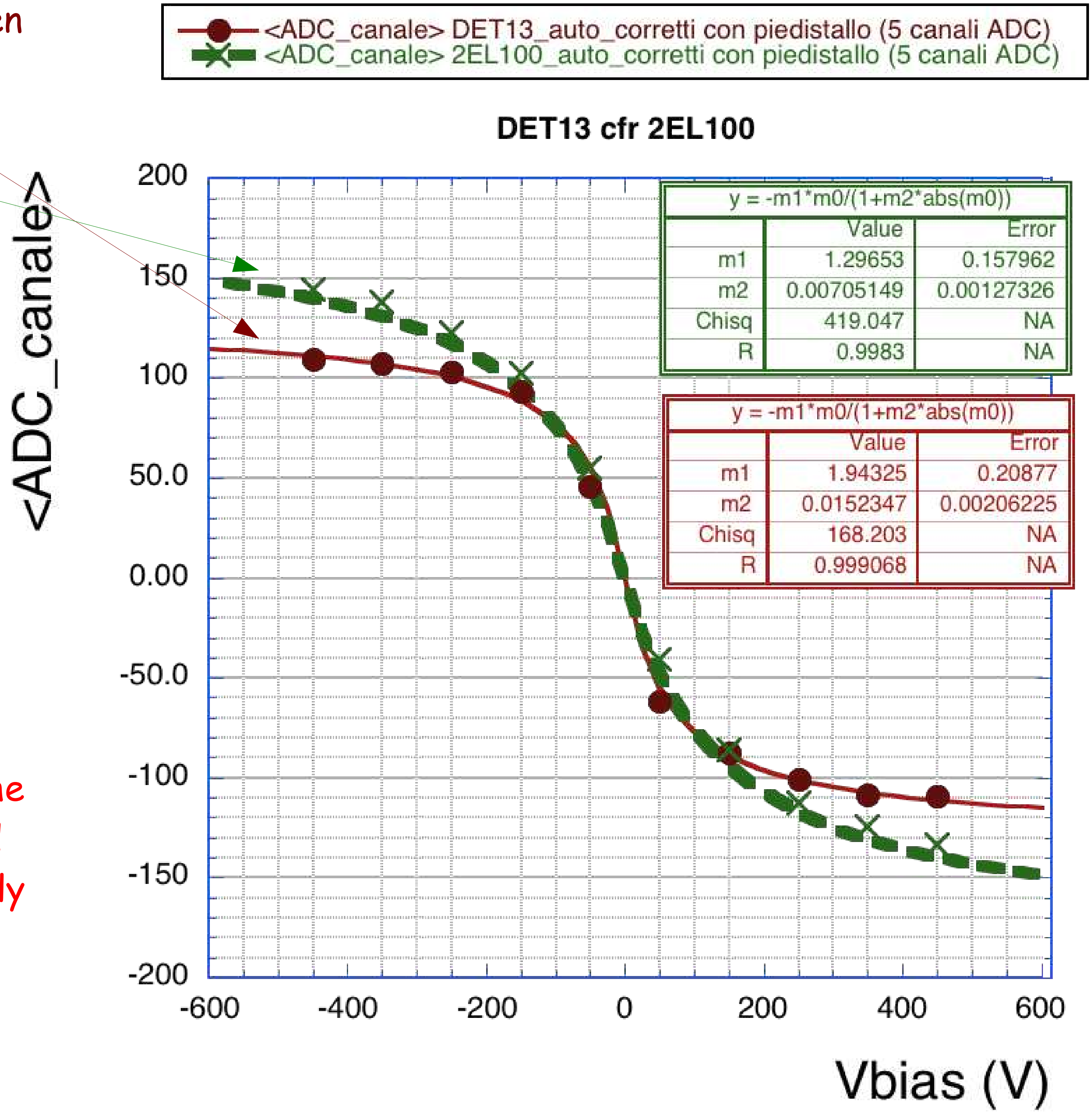
Q_{av} (mV)



y = -m1*m0/(1+m2*abs(m0))

	Value	Error
m1	0.440004	0.0511456
m2	0.014863	0.00206455
Chisq	0.487674	NA
R	0.989079	NA

Comparison between graphite and standard (Ti-Au) contacts



y = -m1*m0/(1+m2*abs(m0))

	Value	Error
m1	1.29653	0.157962
m2	0.00705149	0.00127326
Chisq	419.047	NA
R	0.9983	NA

y = -m1*m0/(1+m2*abs(m0))

	Value	Error
m1	1.94325	0.20877
m2	0.0152347	0.00206225
Chisq	168.203	NA
R	0.999068	NA

Agreement in the mesaurements considering that the graphite contacted sample has a slightly lower thickness