IBIC – ION BEAM INDUCED CHARGE
ion microprobe technique for testing diamond detectors, application examples, perspectives

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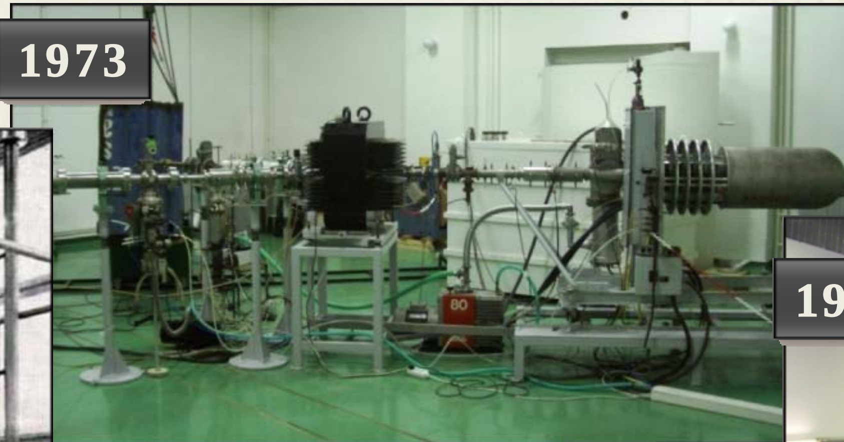
Ruđer Bošković Institute

1. Facilities
2. IBIC
3. Application examples

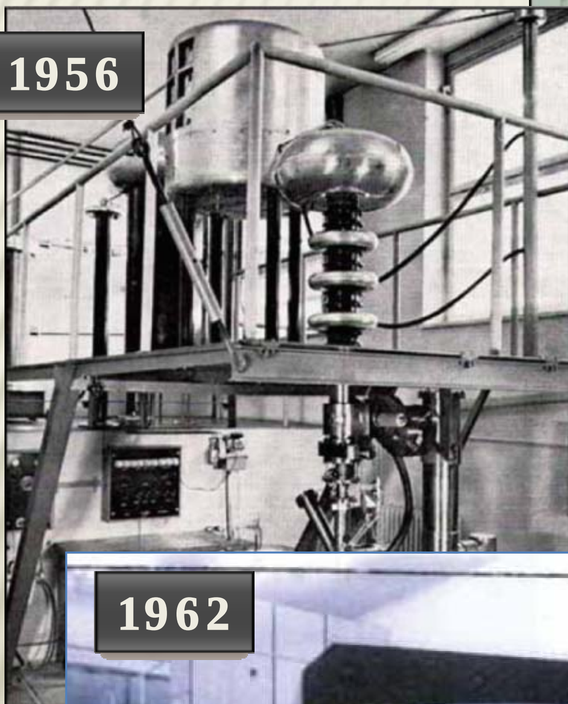
1. RBI ACCELERATORS

Ruđer Bošković Institute

1973



1956



1987

2009

1962

2005

1. TANDEM ACCELERATOR FACILITY

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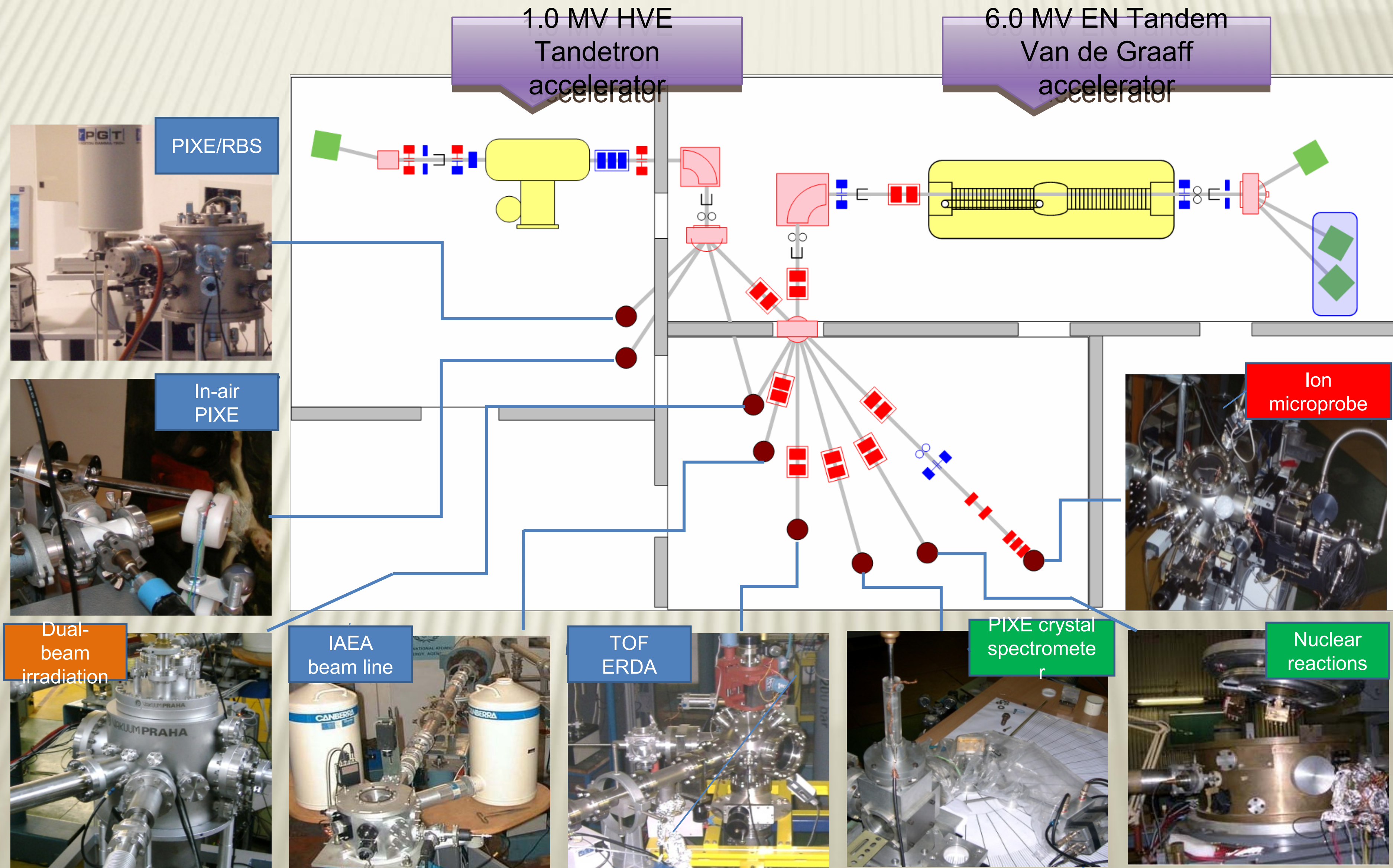

ION BEAM ANALYSIS

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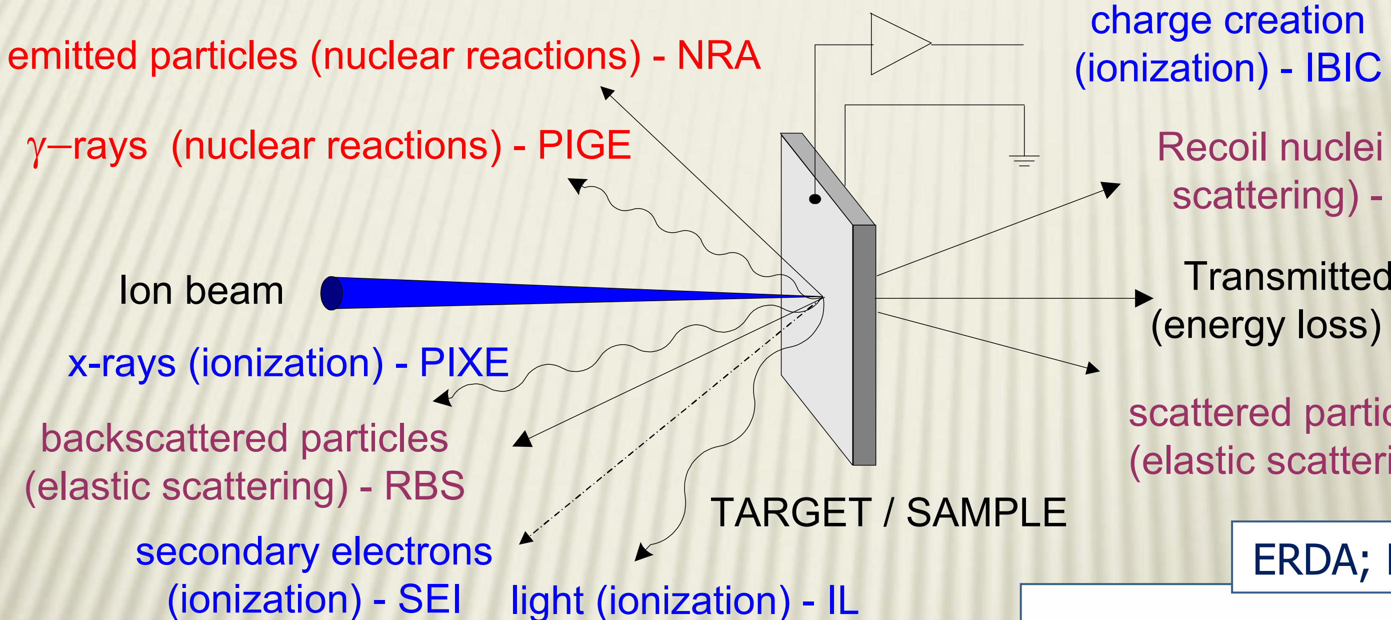
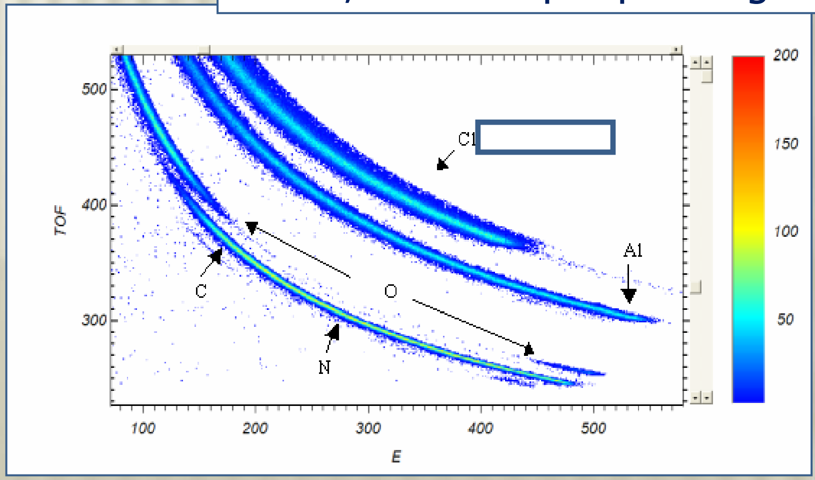
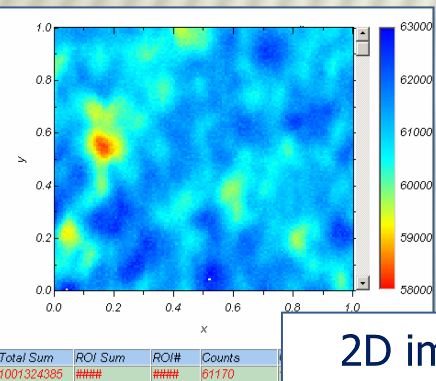
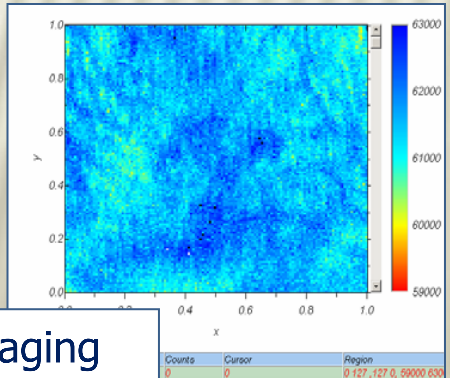
UNIQUENESS: numerous processes



ERDA; RBS – depth profiling

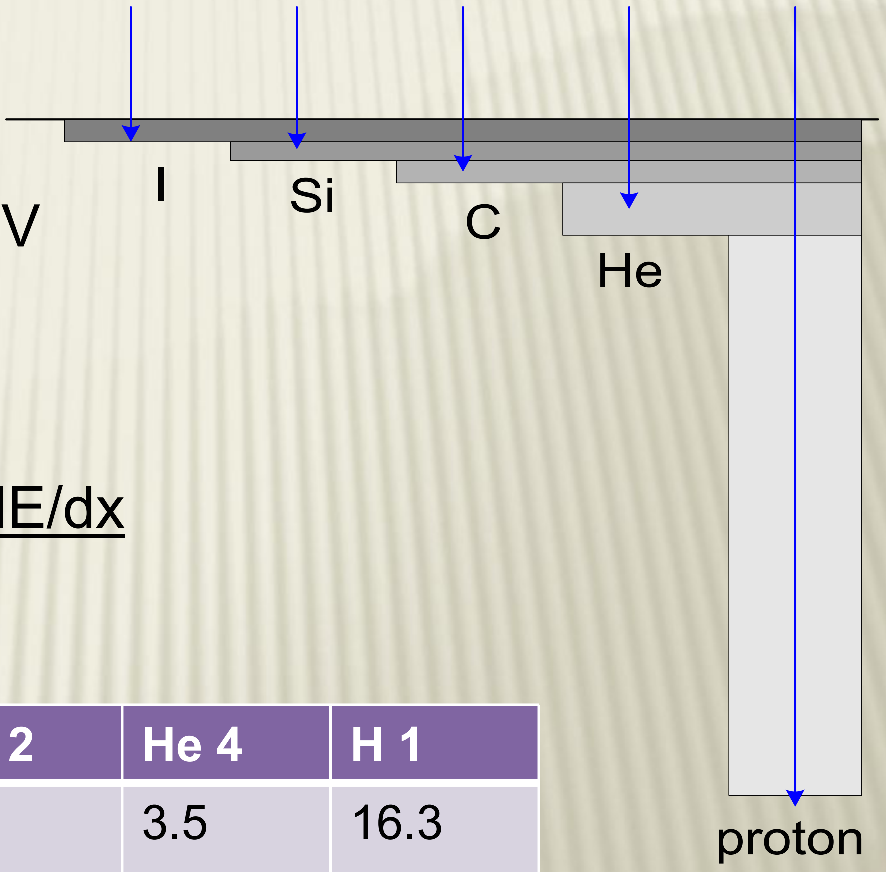






2D imaging

1. ACCELERATORS – Available ion beams

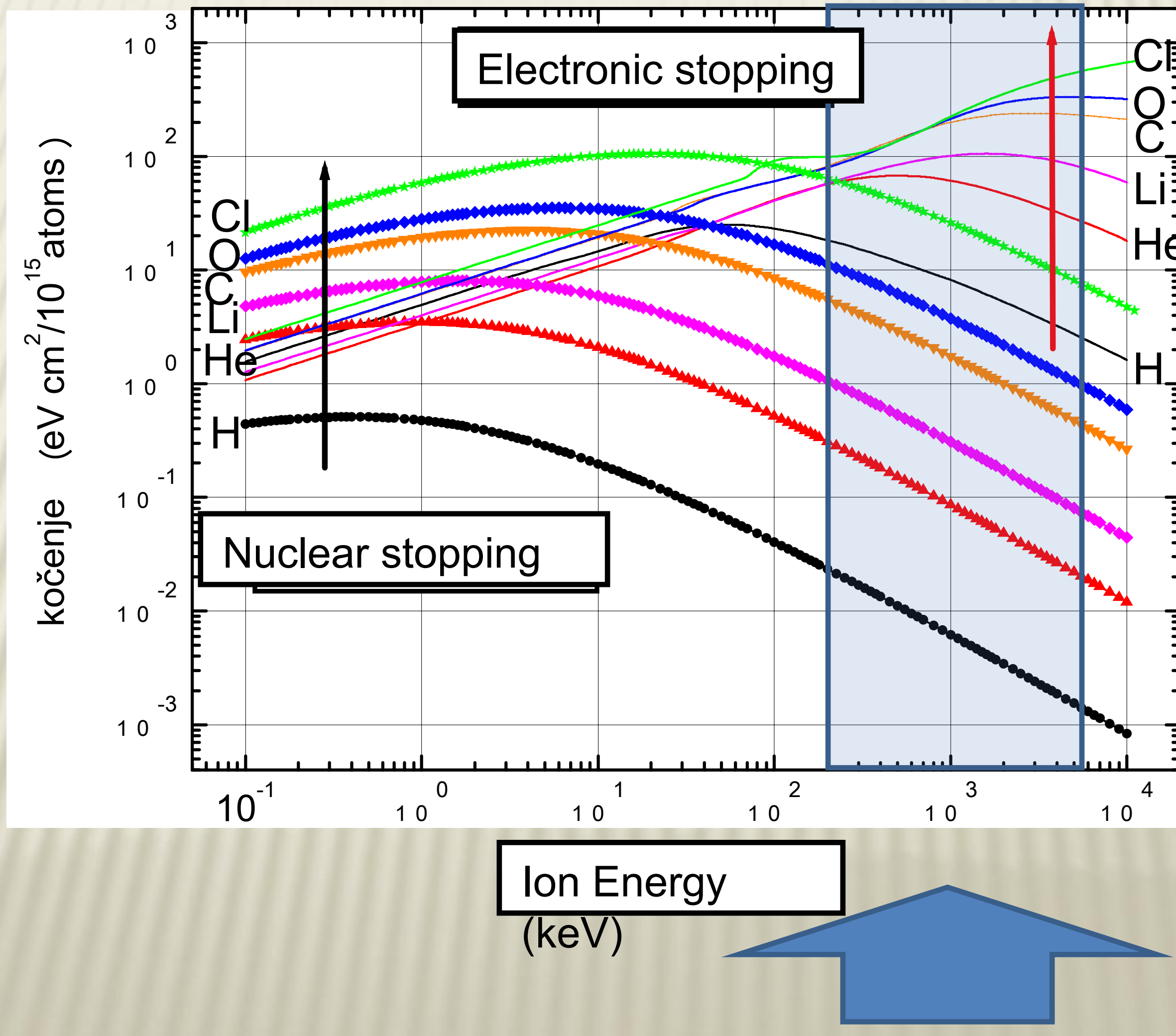


Terminal voltages – 0.1 to 12 MV
Ion sources – sputtering,
RF alphatross, duoplasmatron

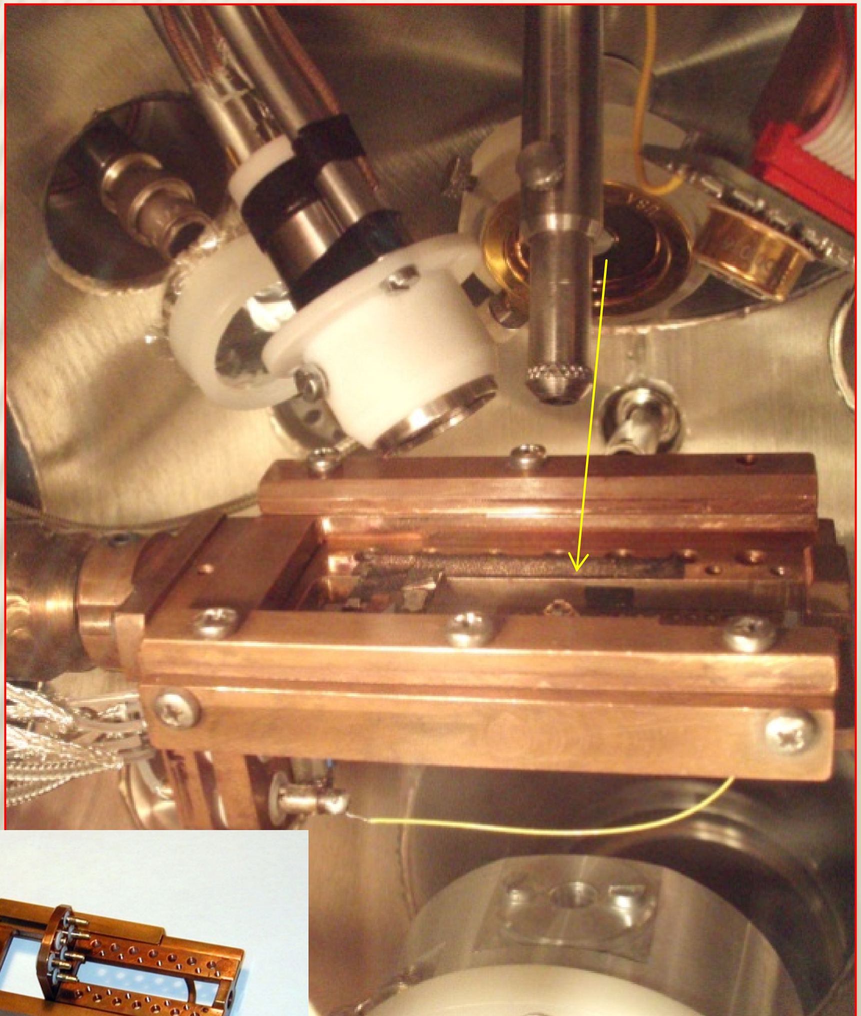
Good selection of ion ranges / dE/dx !!

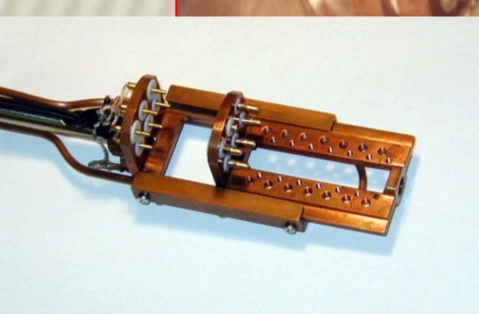
Silicon	I 127-	Si 28	C 12	He 4	H 1
Range(µm) E=1 MeV	0.37	1.13	1.6	3.5	16.3
Range (µm) E=10 MeV	3.7	4.8	9.5	69.7	709

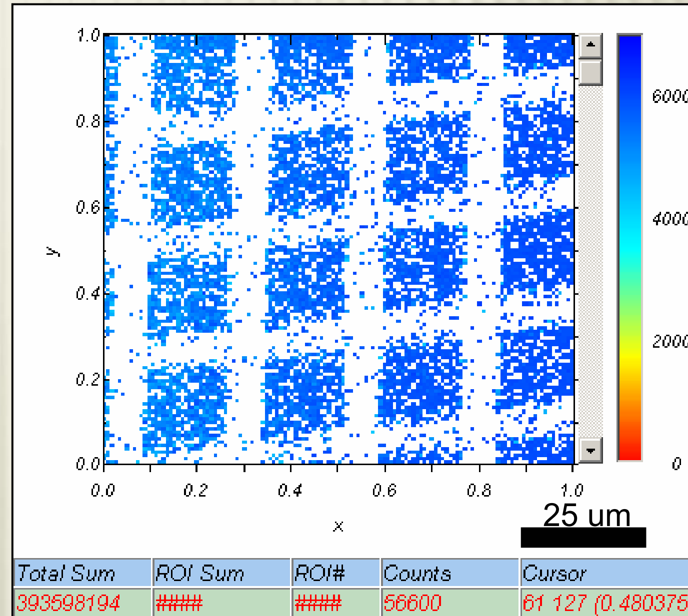
1. ACCELERATORS – Available ion beams



1. ACCELERATORS – heavy ion microprobe







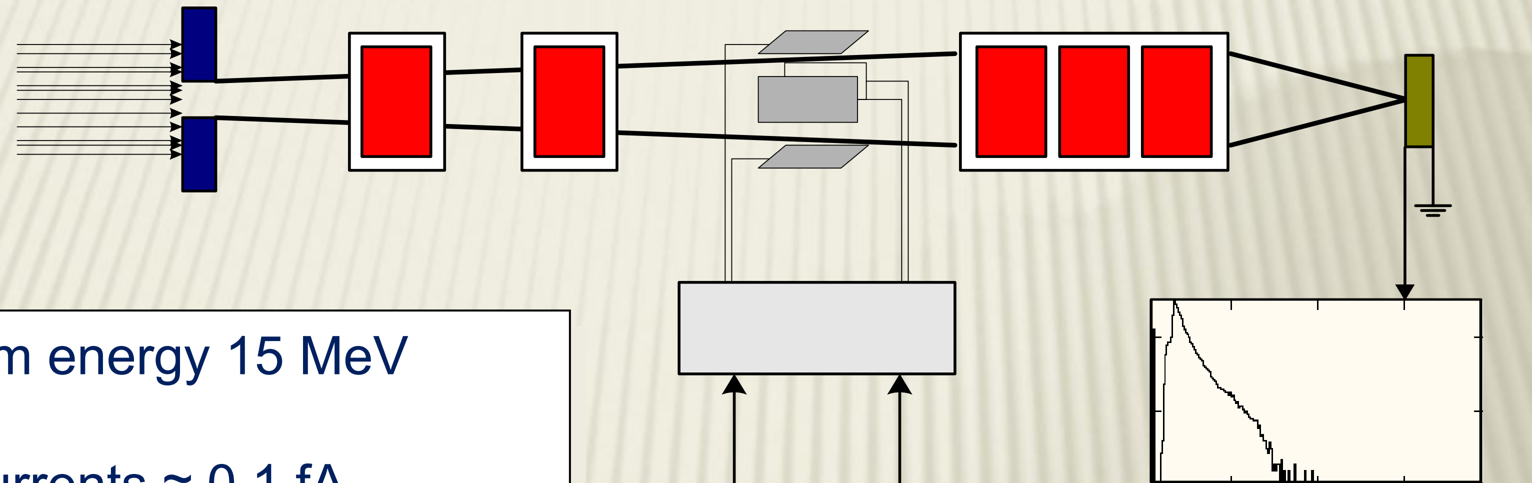
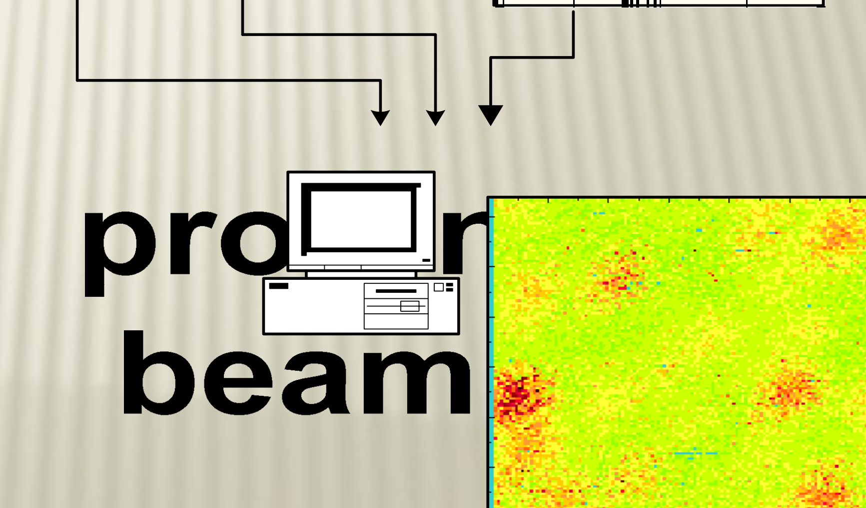
Transmission image of 11 MeV C^{3+} through Cu grid

Typical resolution 1 um
Best resolution 0.4 um

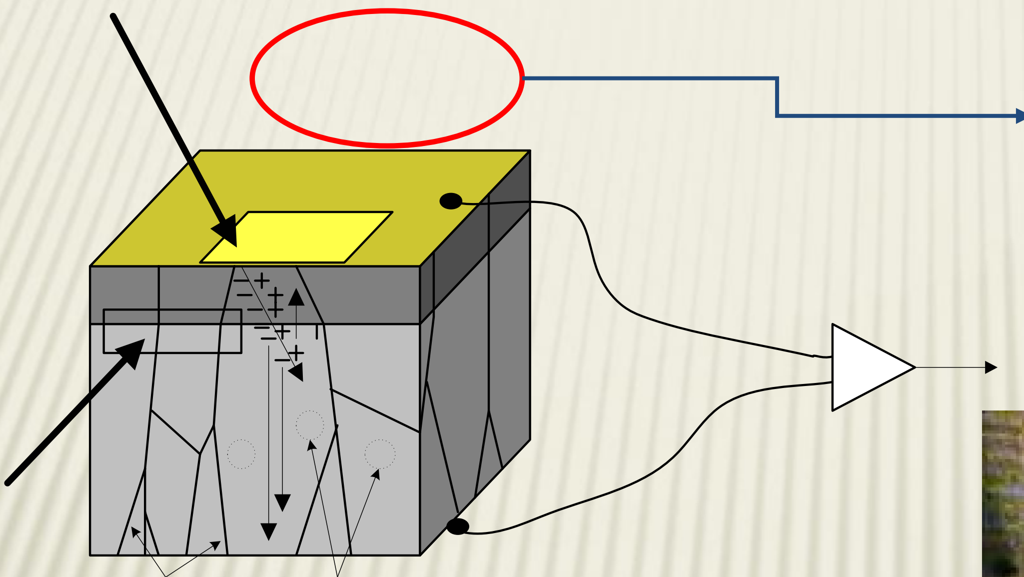
1. ACCELERATORS – heavy ion microprobe

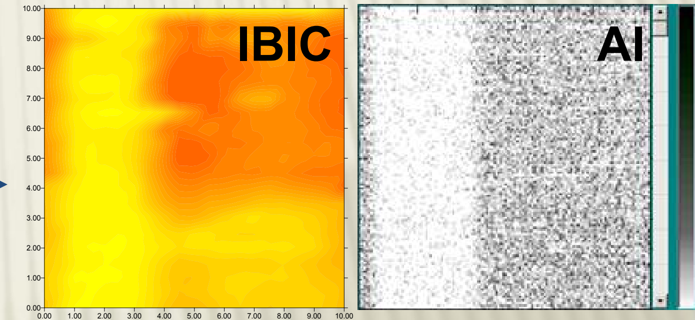
- Maximum energy 15 MeV ME/q2
- Beam currents ≈ 0.1 fA
- Ion hit time can be determined by ~ 1 ns resolution

by ~ 1 ns resolution

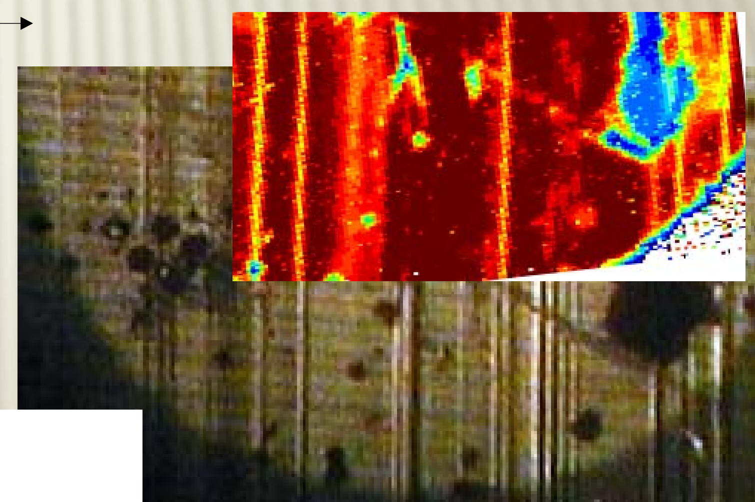



2. IBIC – ION BEAM INDUCED CHARGE





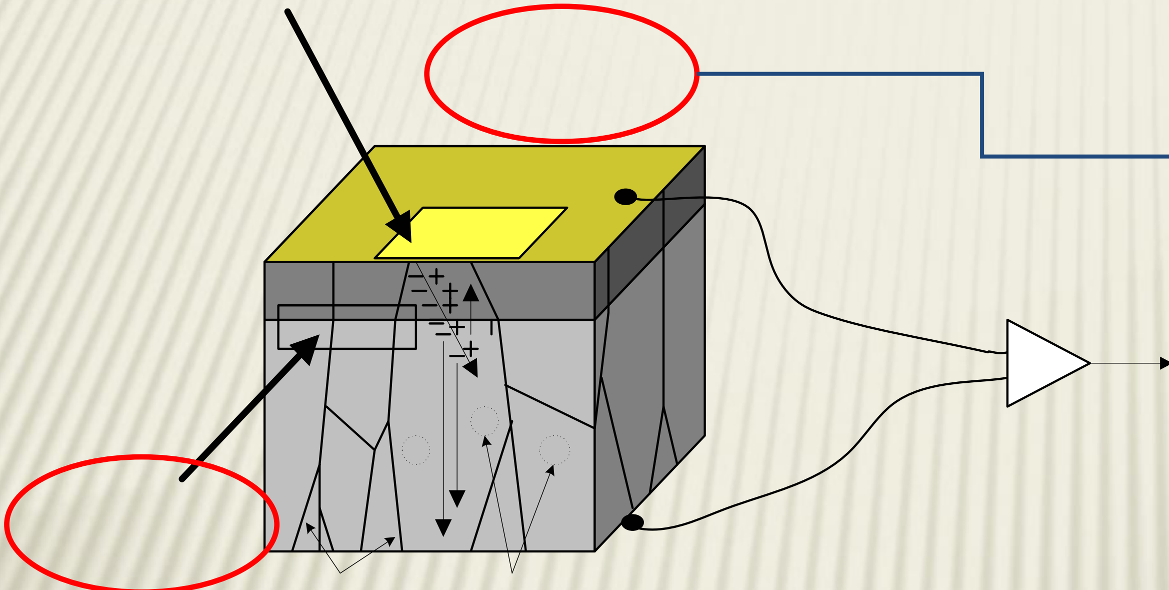
amorphous silicon

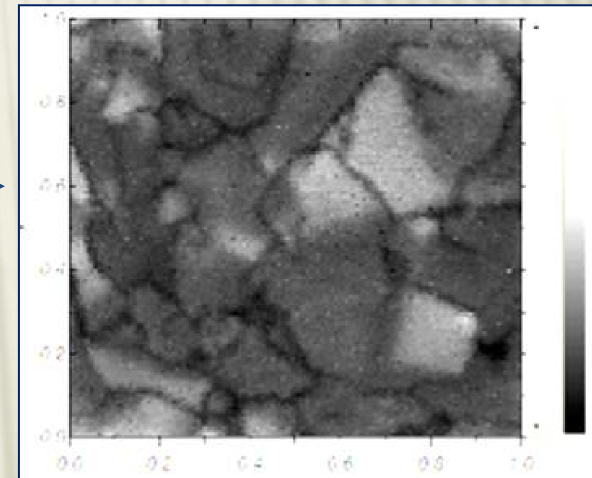

EFG silicon

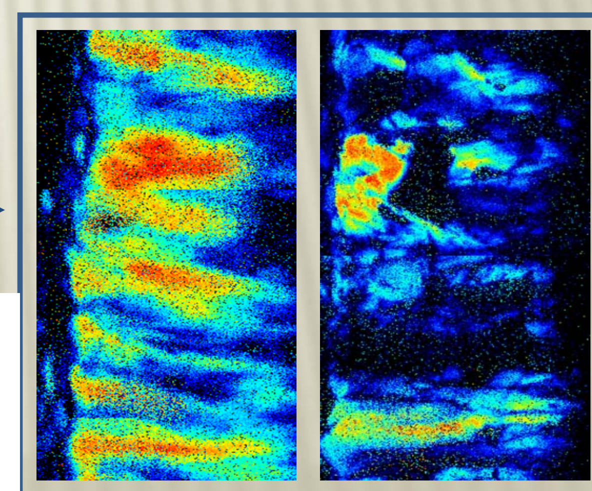
IBIC - single ion technique for imaging of microscopic distribution of charge transport properties !
- Imaging of grain boundaries, defects (such as dislocations), electric field (polarization),...

Front

2. IBIC – ION BEAM INDUCED CHARGE







CVD diamond (1997)

Fronta

IBIC - single ion technique for imaging of microscopic distribution of charge transport properties !

- Imaging of grain boundaries, defects (such as dislocations), electric field (polarization),...

2. IBIC – ION BEAM INDUCED CHARGE

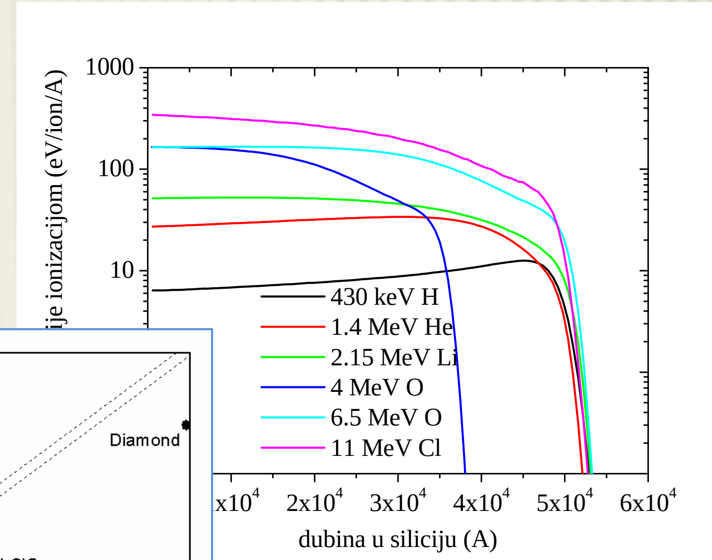
a) Ions lose their energy dE/dx

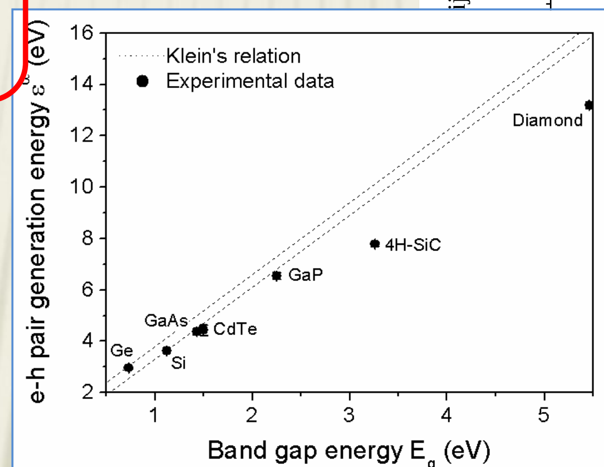
b) Creation of charge pairs e/h

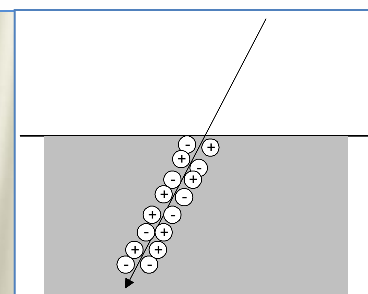
c) Charge transport:
- Drift - in electric field
- Diffusion

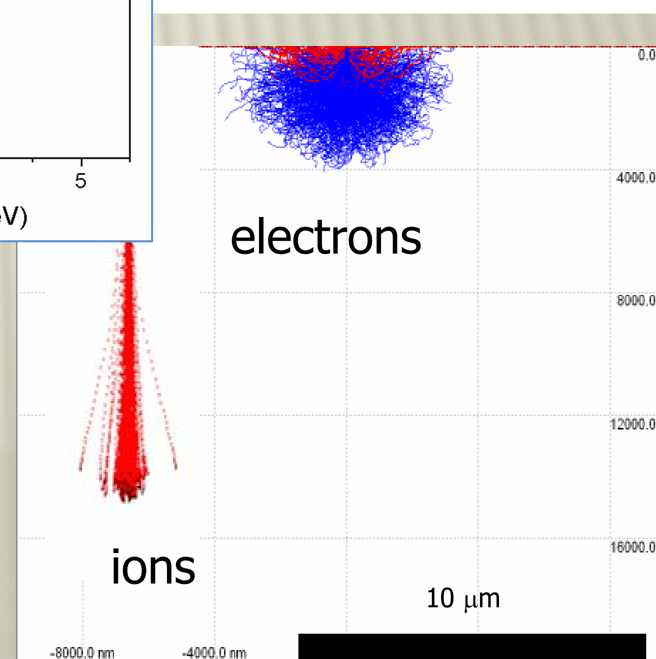
d) Induced charge

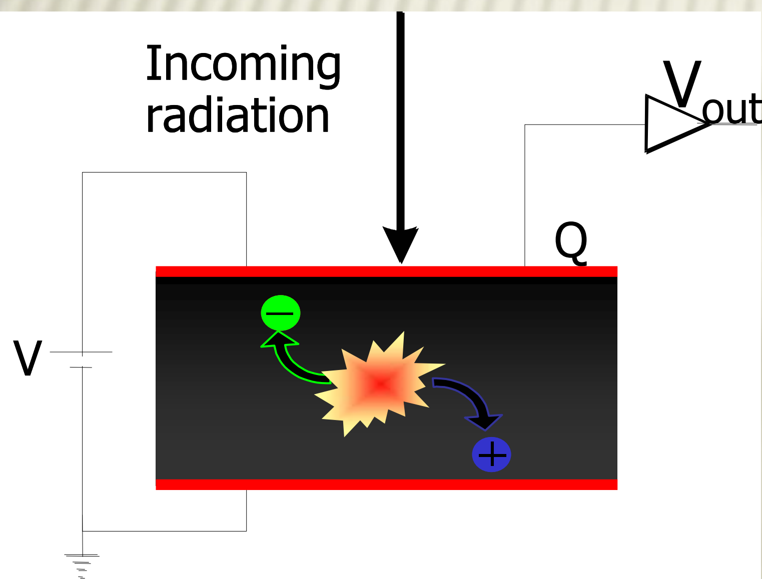
e) IBIC signal











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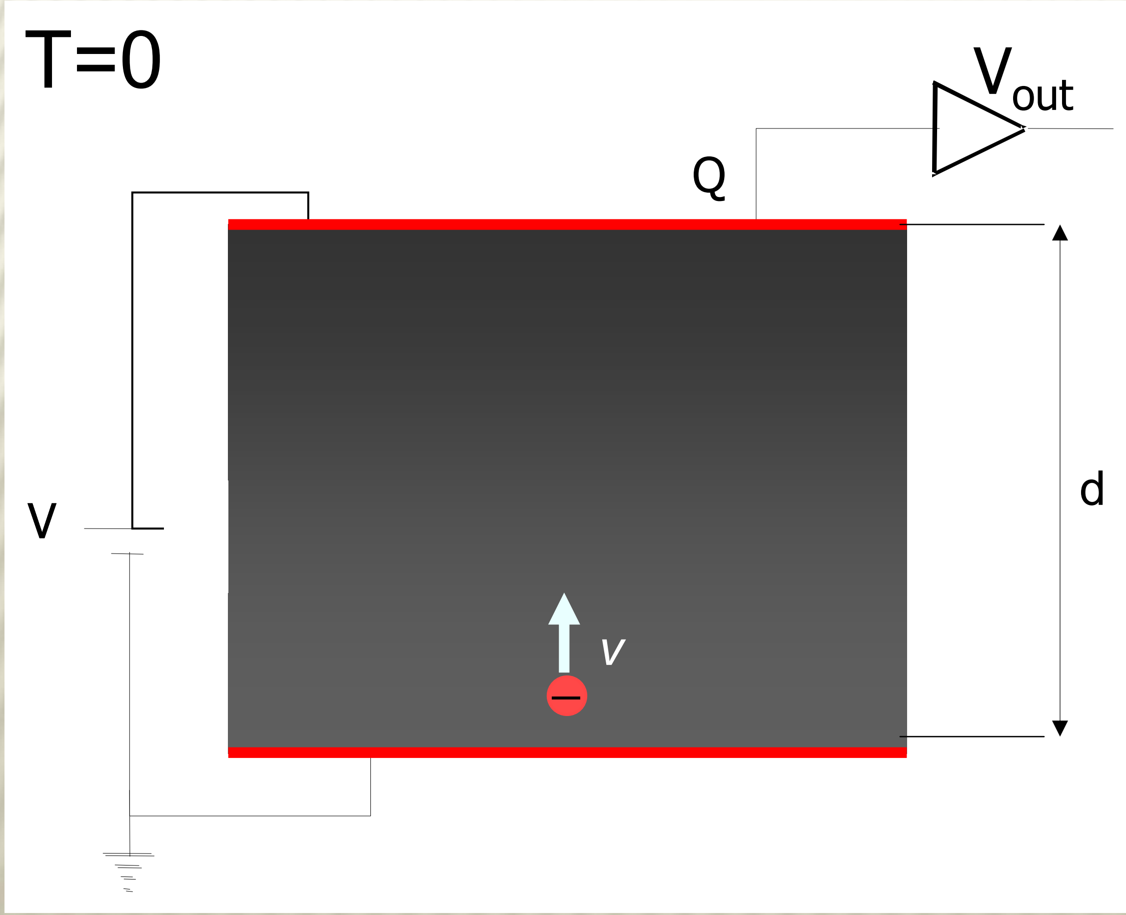
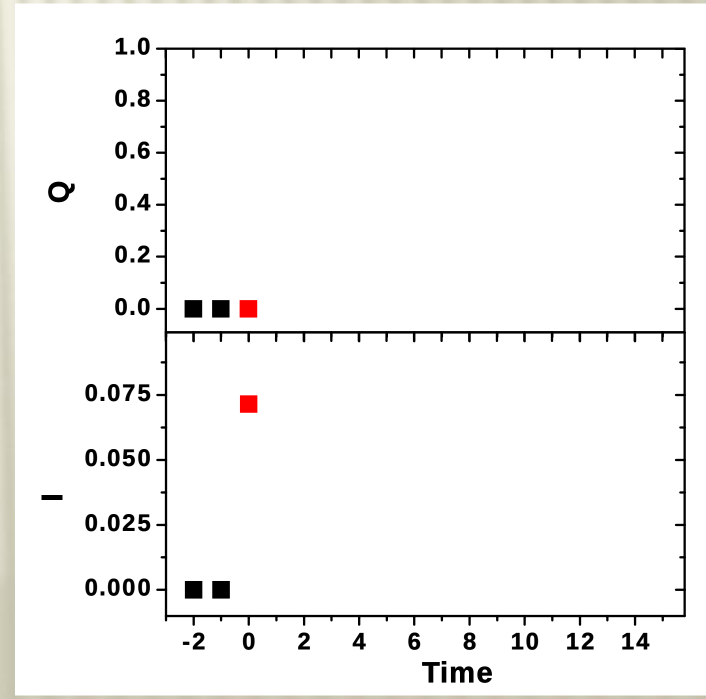
Induced current $I(t) = q \cdot \frac{v}{d}$

Induced charge $Q(t) = \int_0^T I(t)dt$



W. Shockley, J. Appl. Phys. 9 (1938) 635.
S. Ramo, Proc. I.R.E. 27 (1939) 584.



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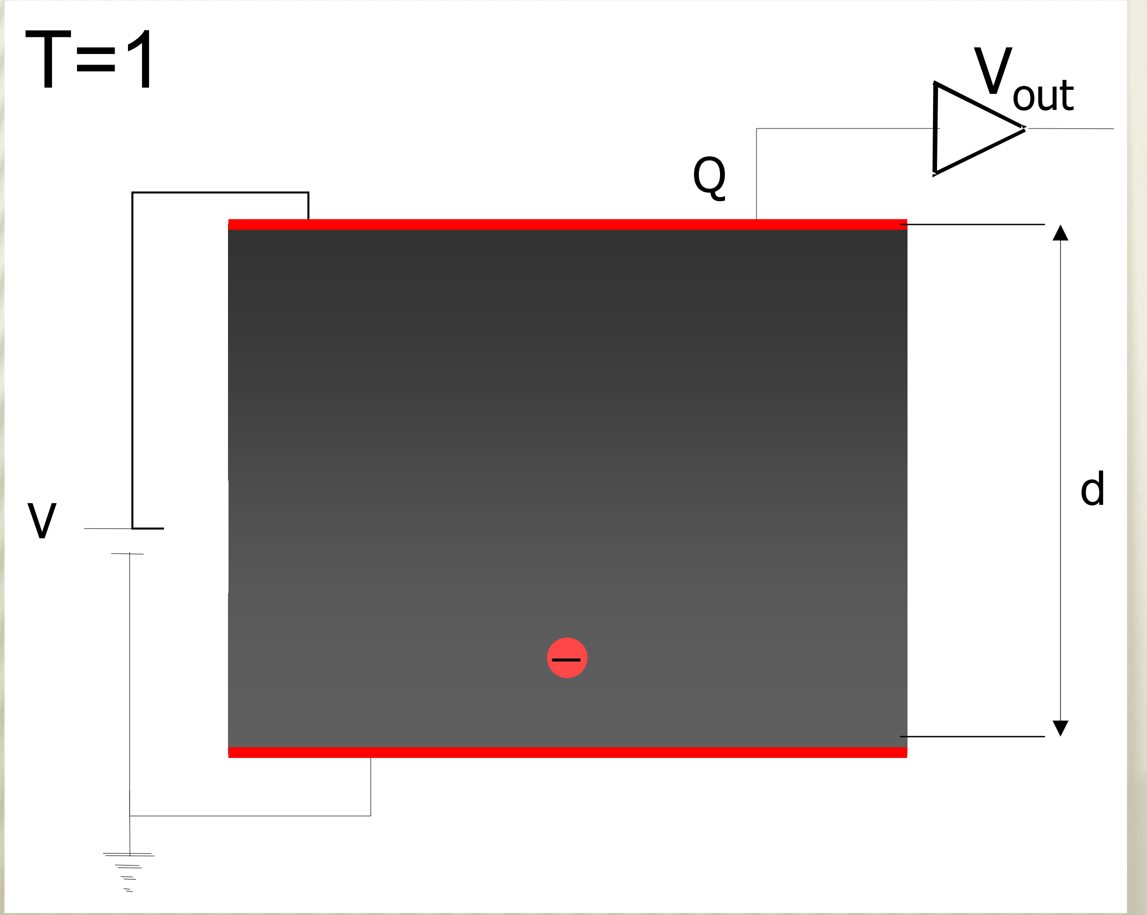

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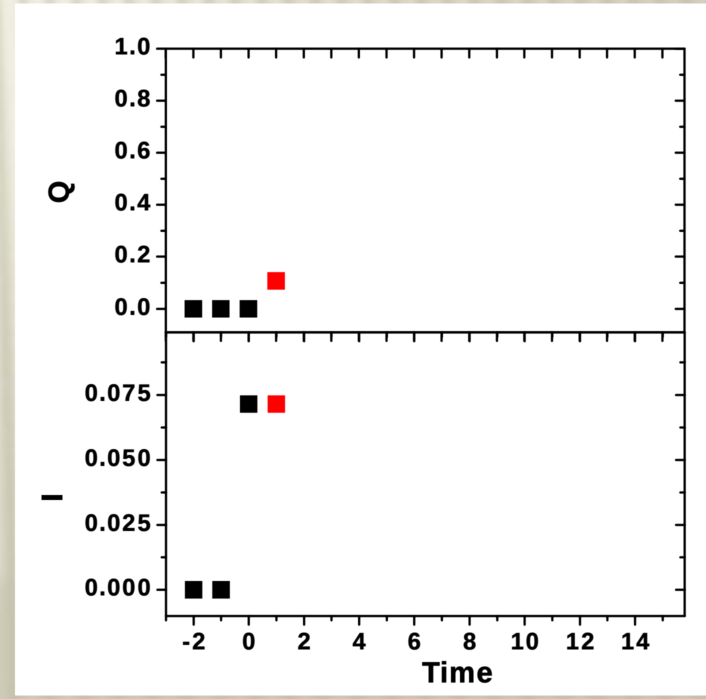

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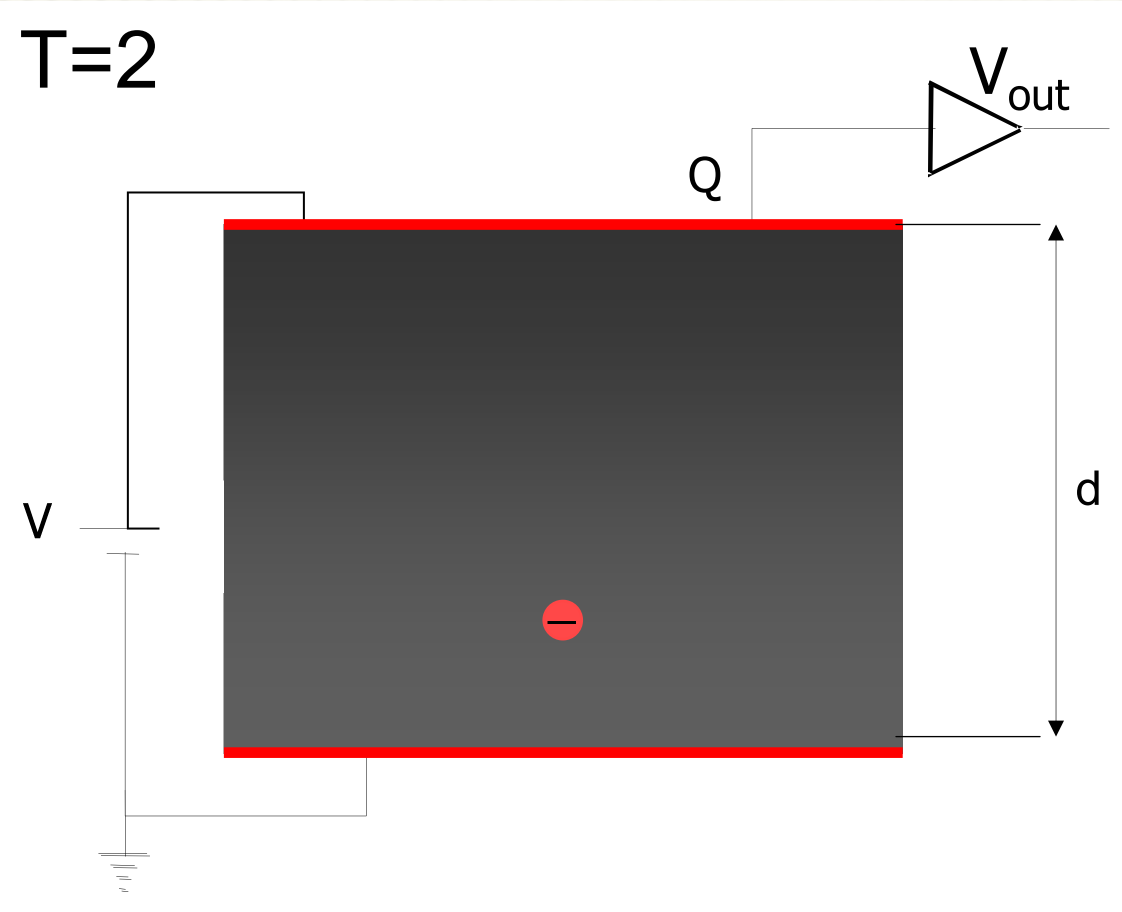

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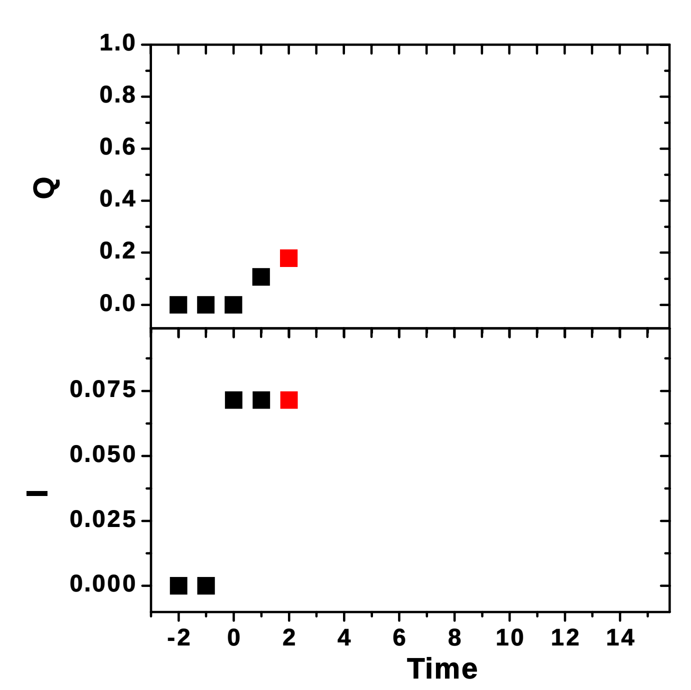

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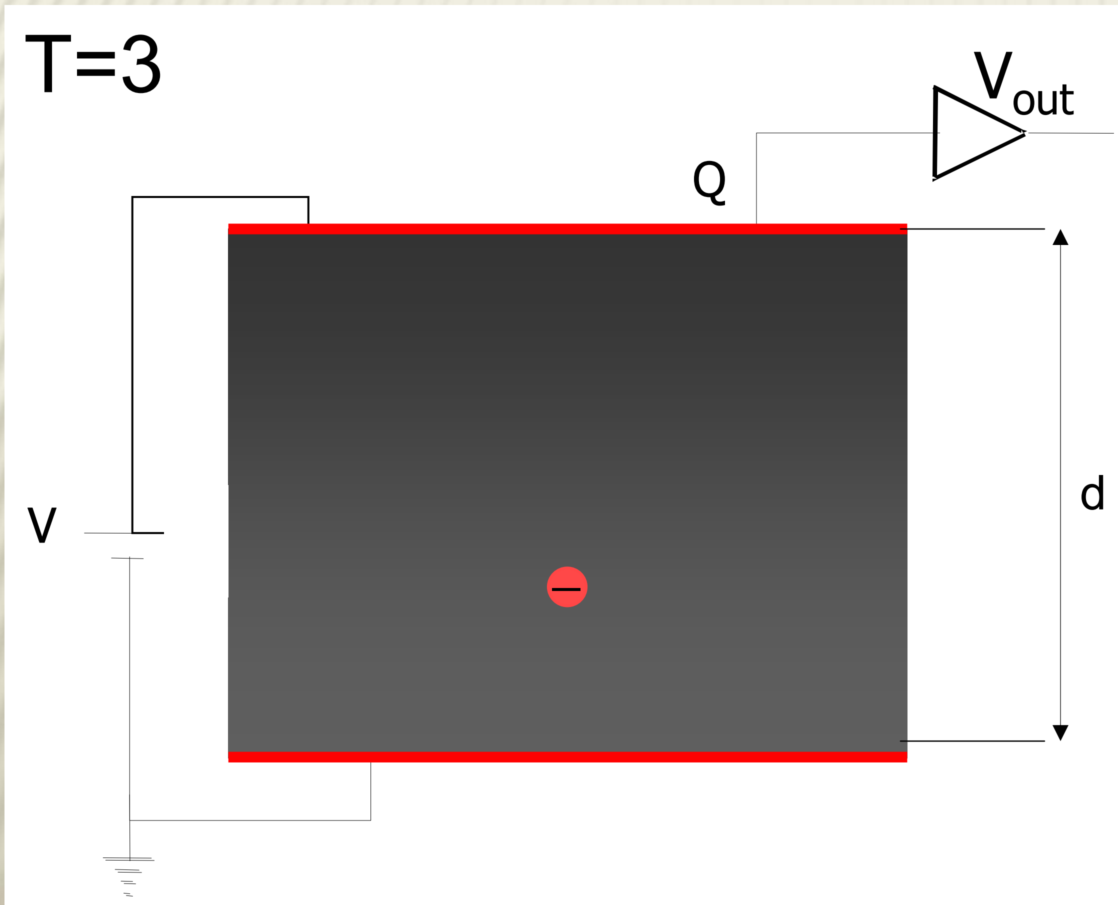

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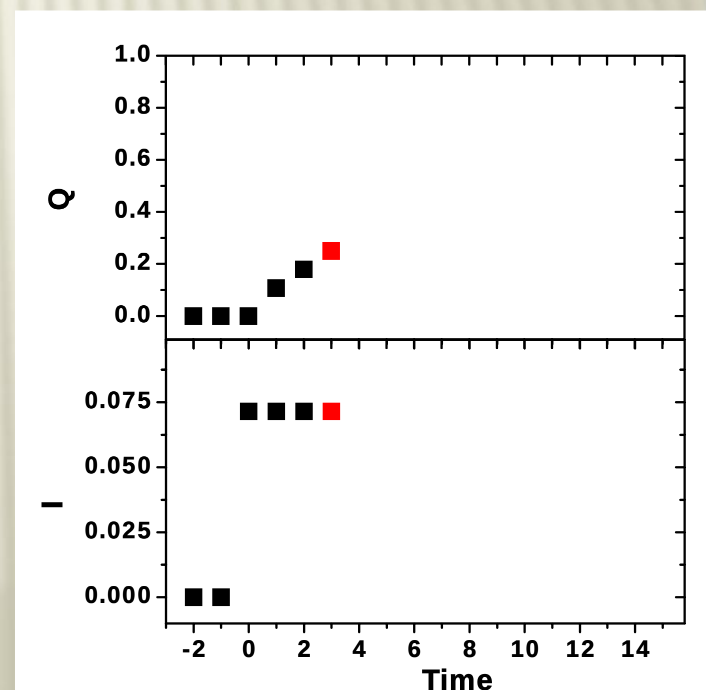

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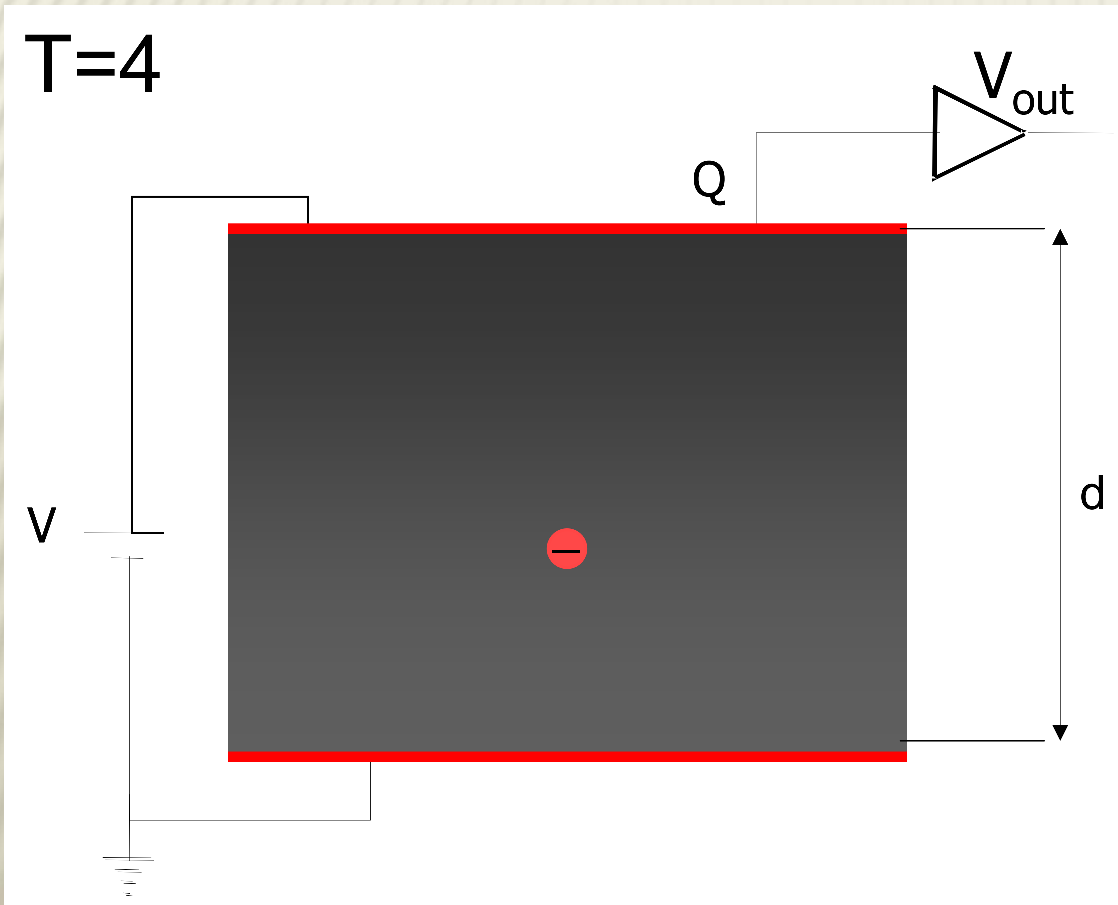

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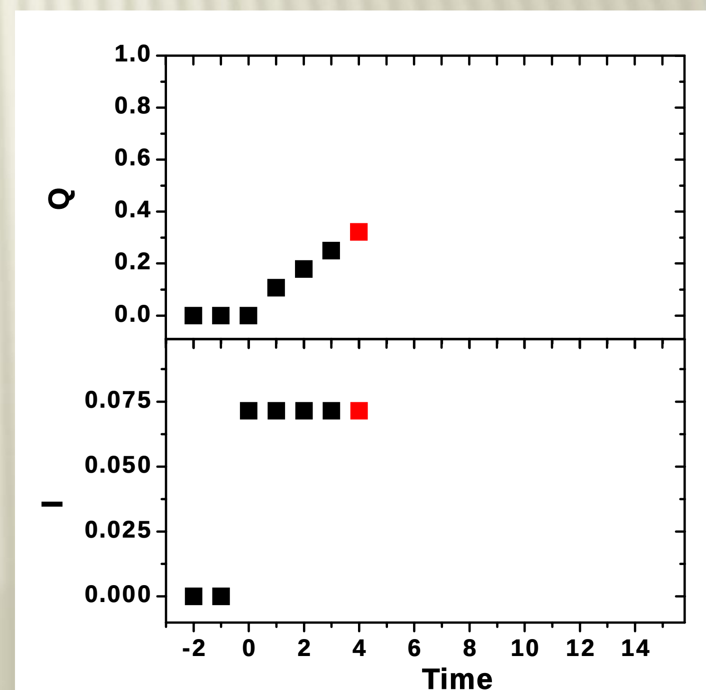

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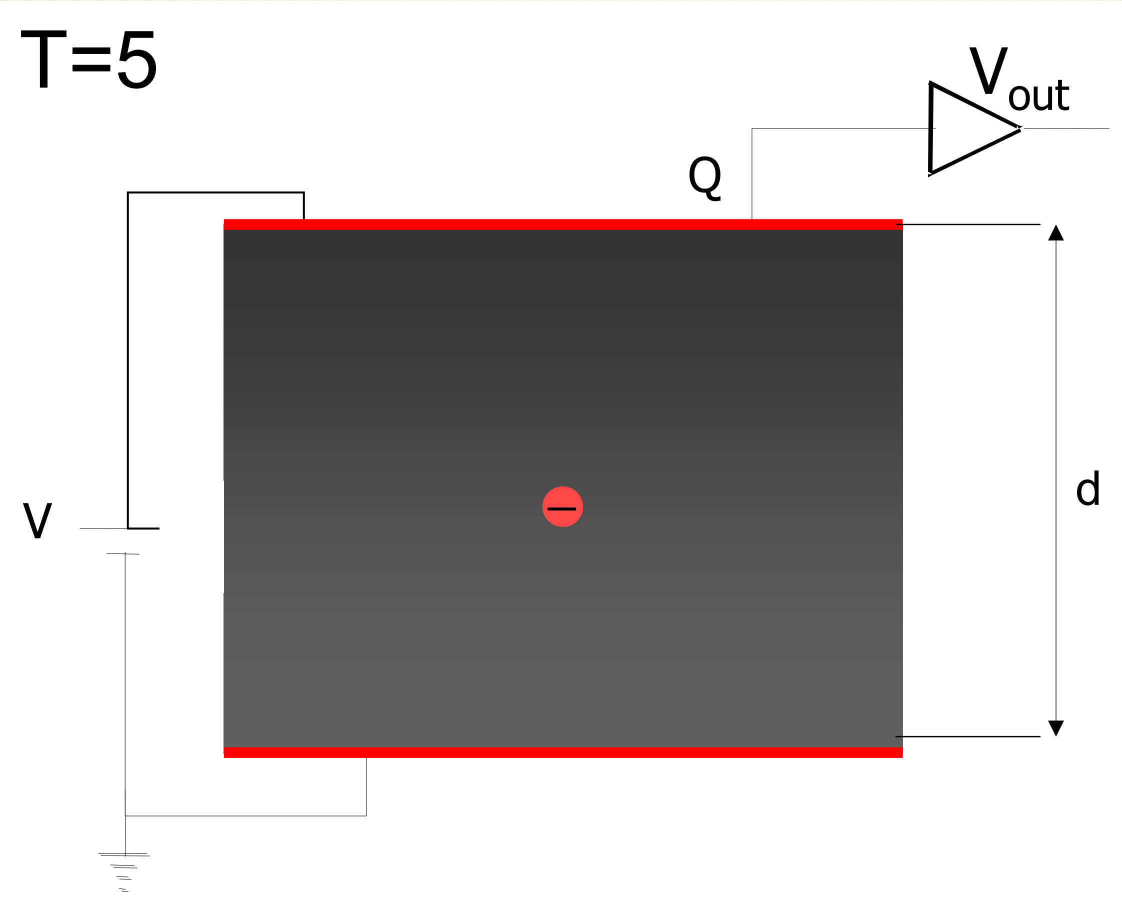

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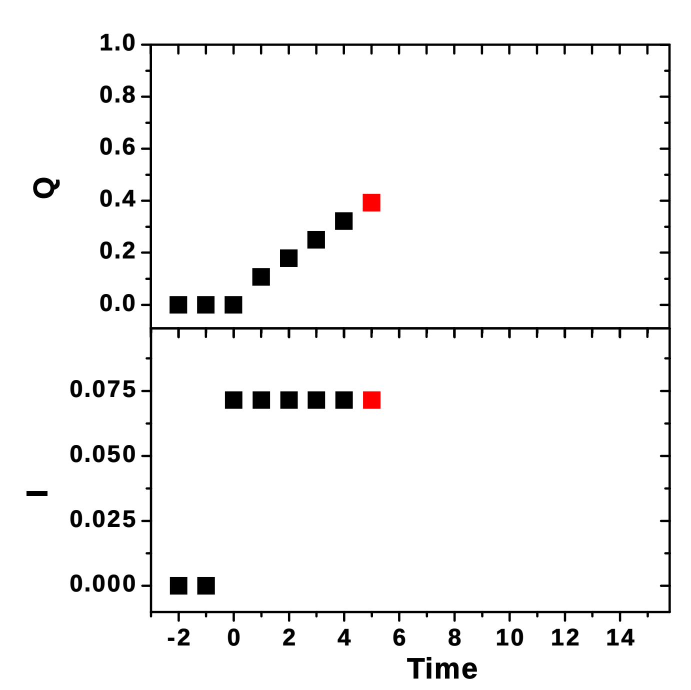

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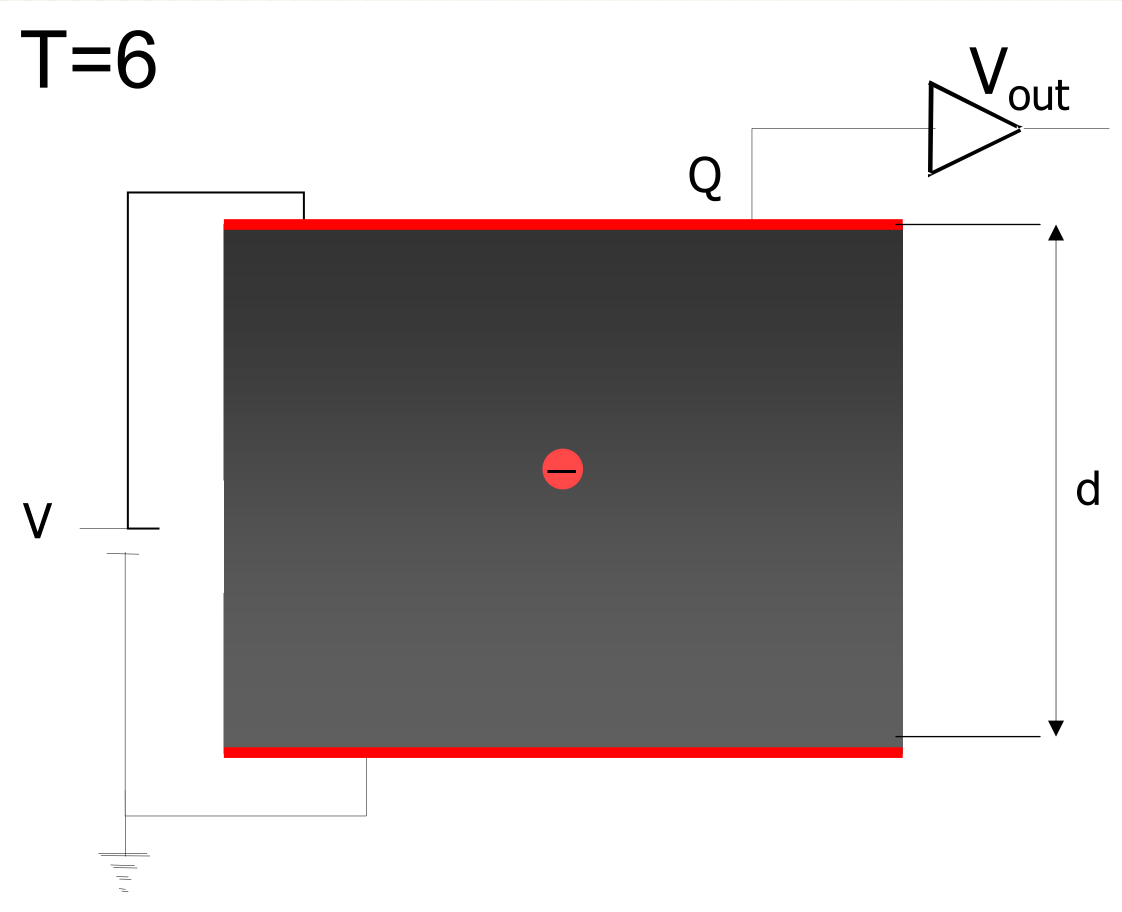

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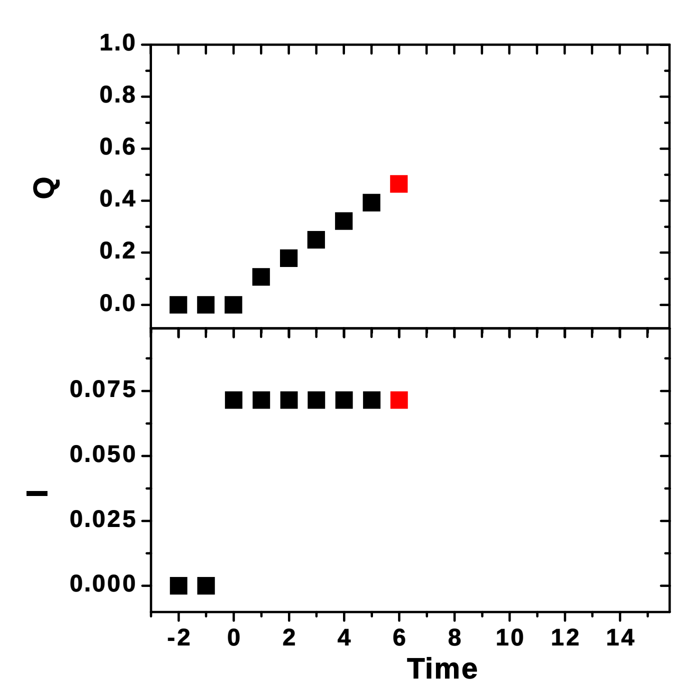

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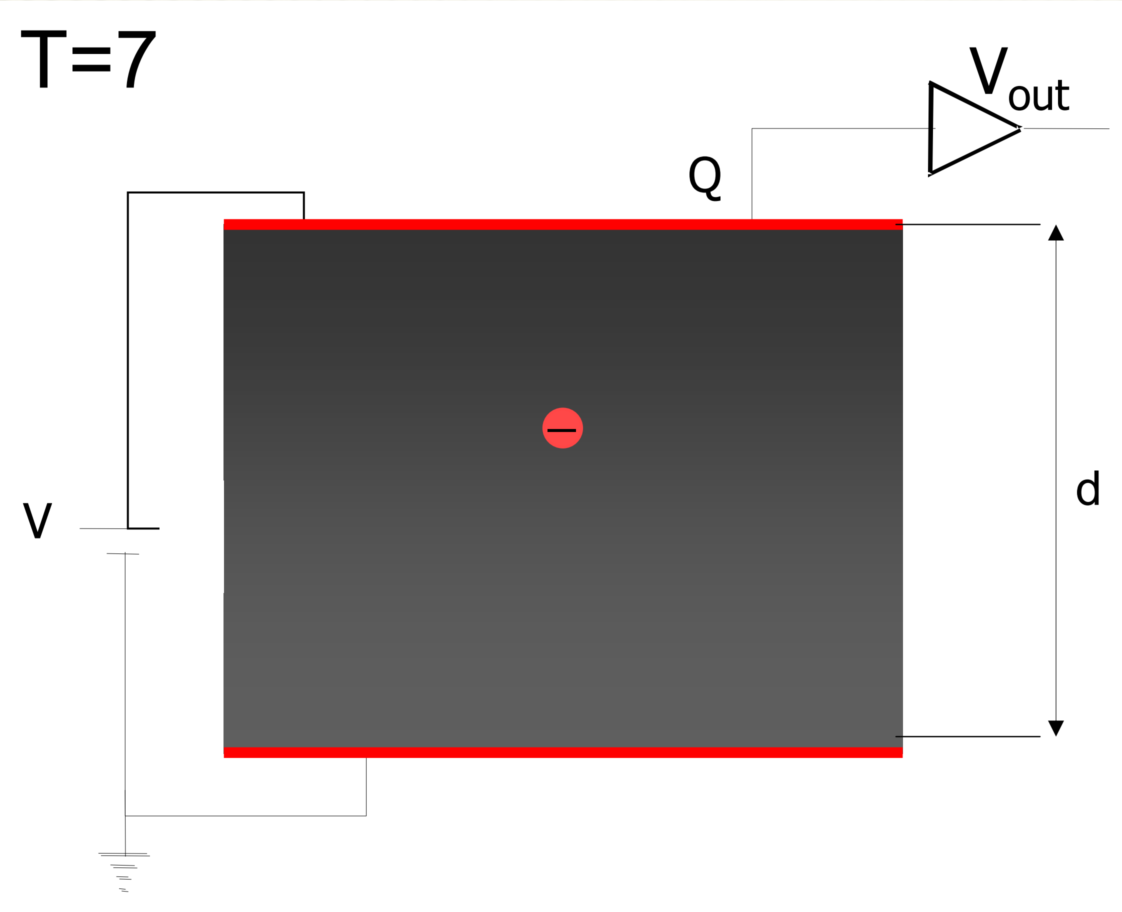

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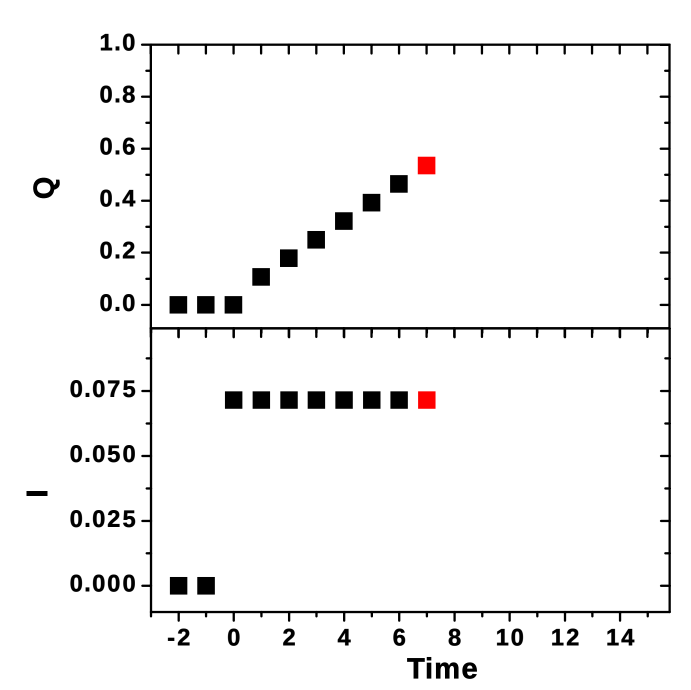

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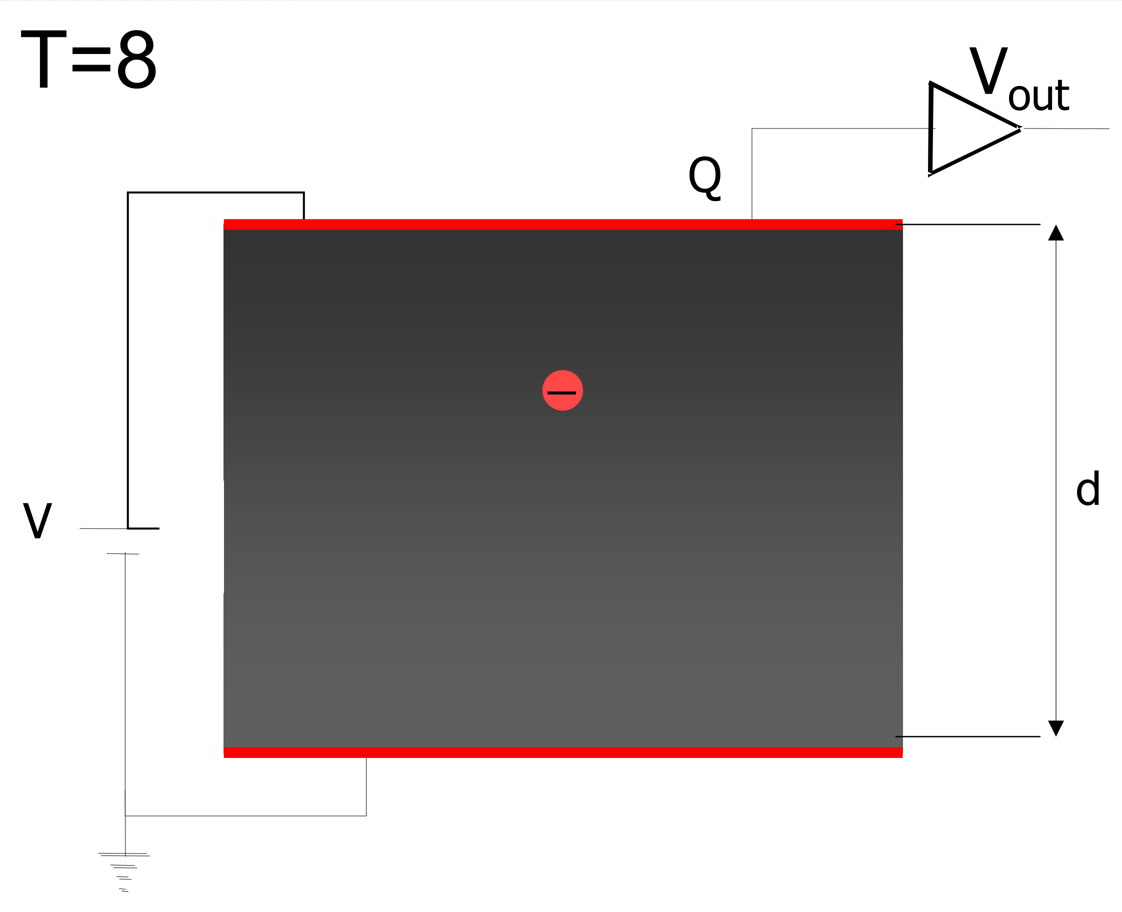

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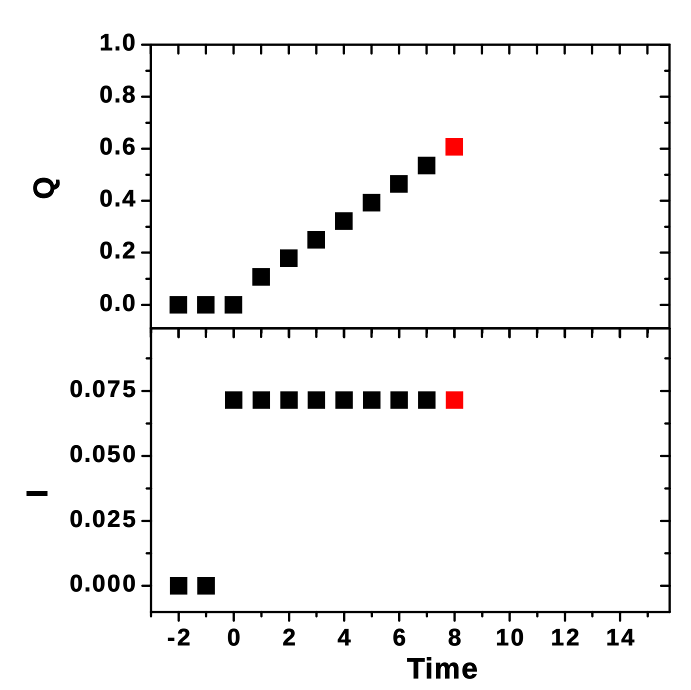

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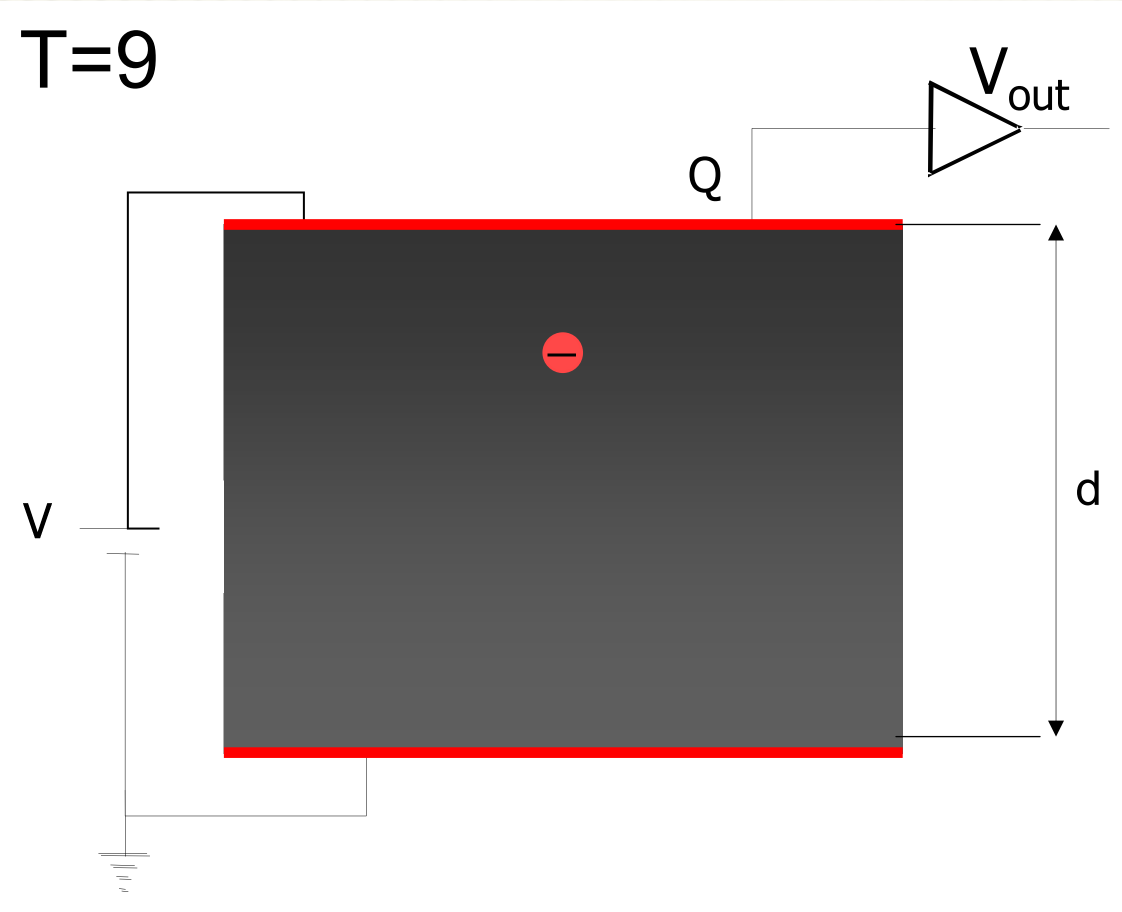

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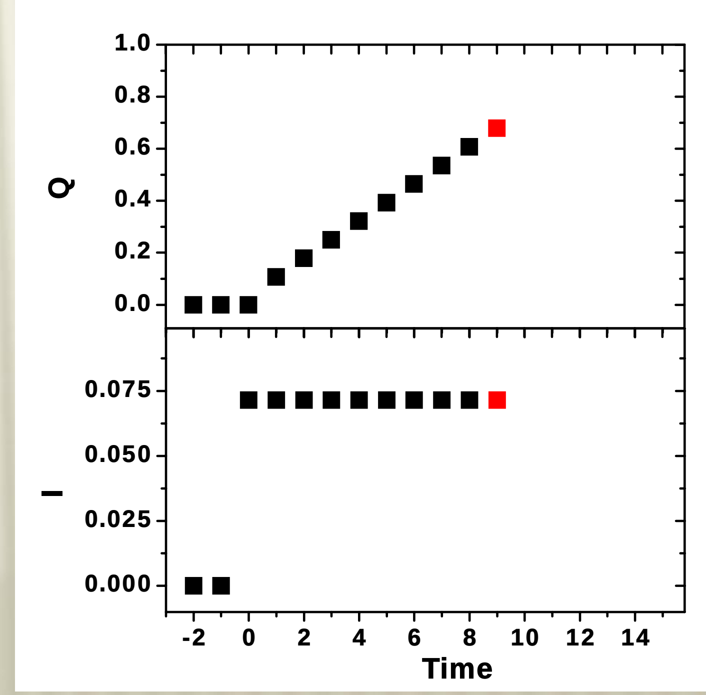

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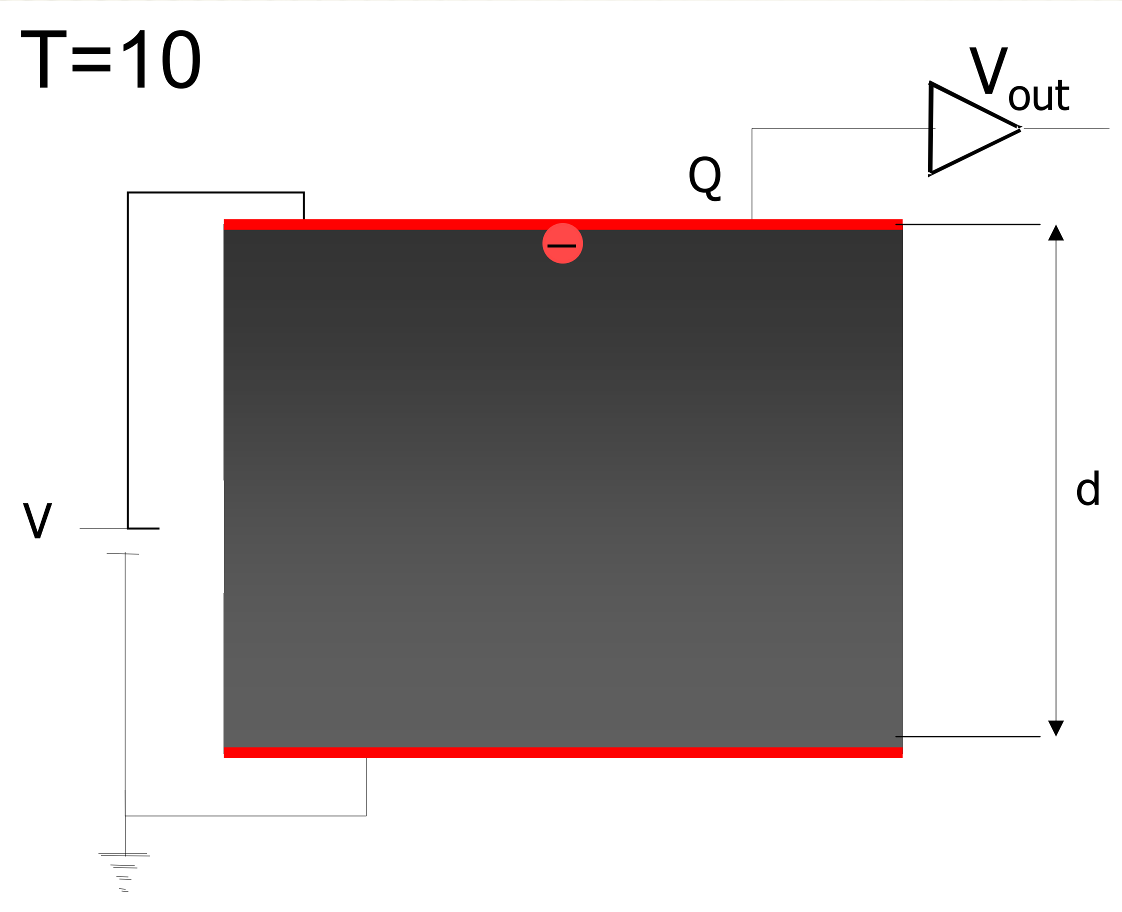

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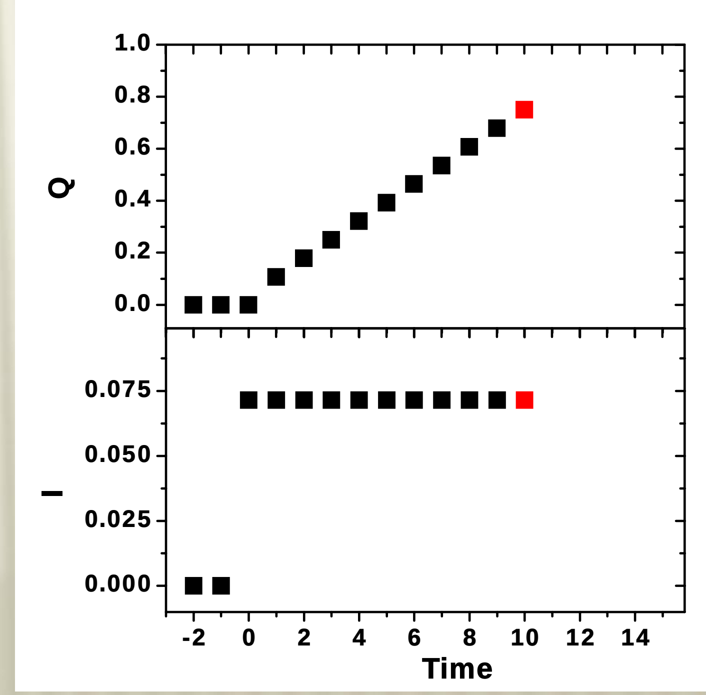

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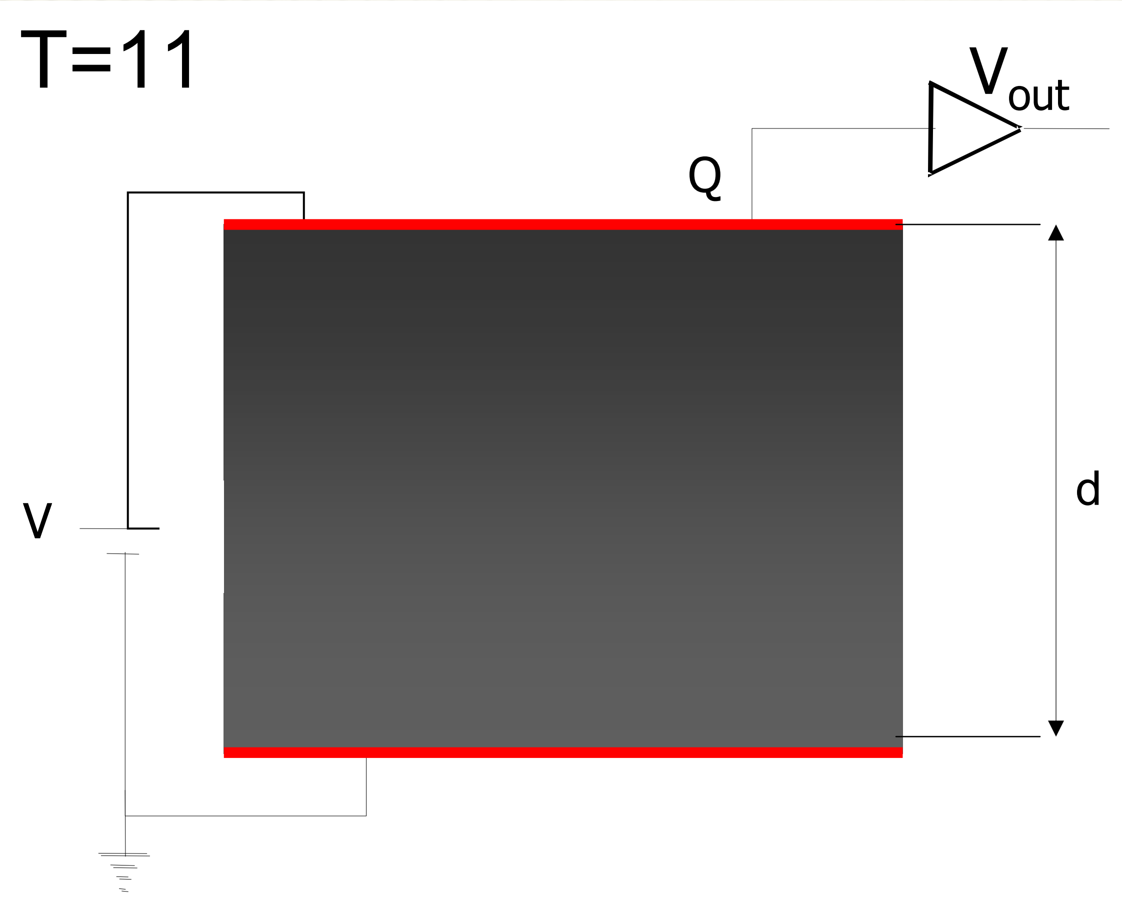

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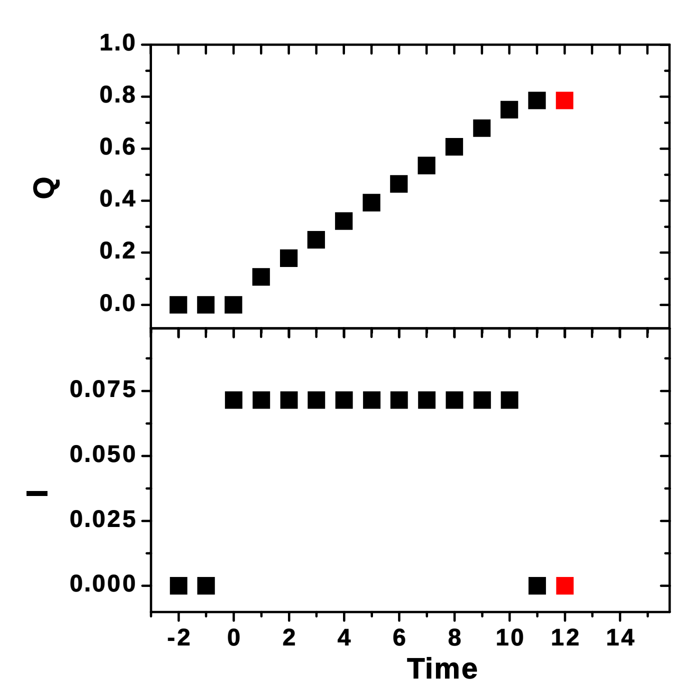
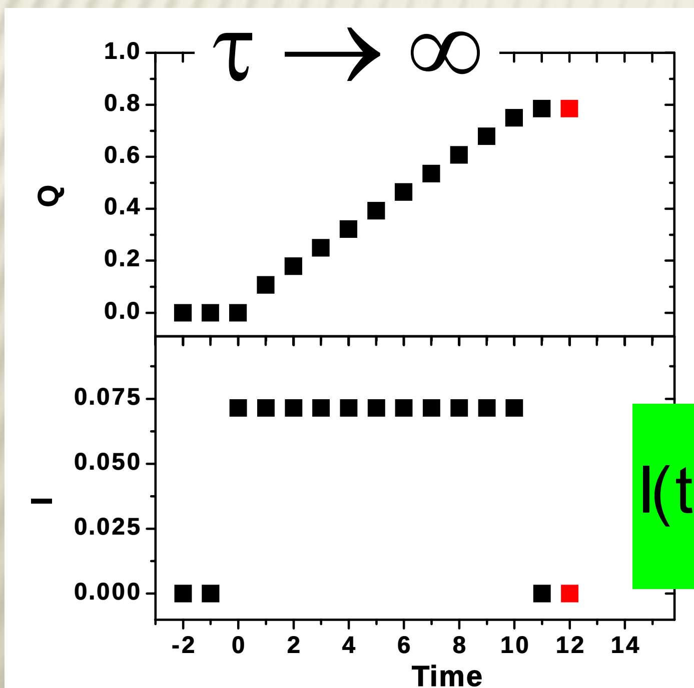


2. IBIC – ION BEAM INDUCED CHARGE

τ - charge carrier lifetime

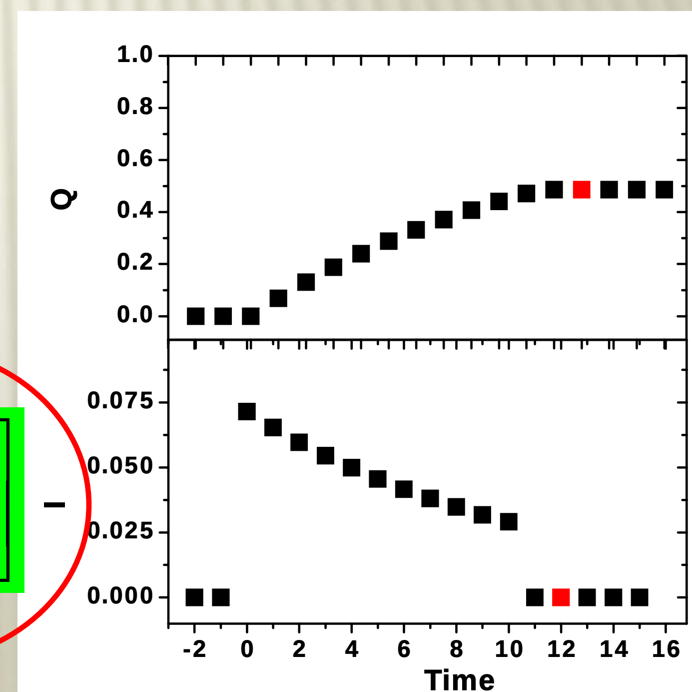
Velocity; $v = \mu E = d/T_R$

Mobility; $\mu = d^2/(T_R * V_{Bias})$



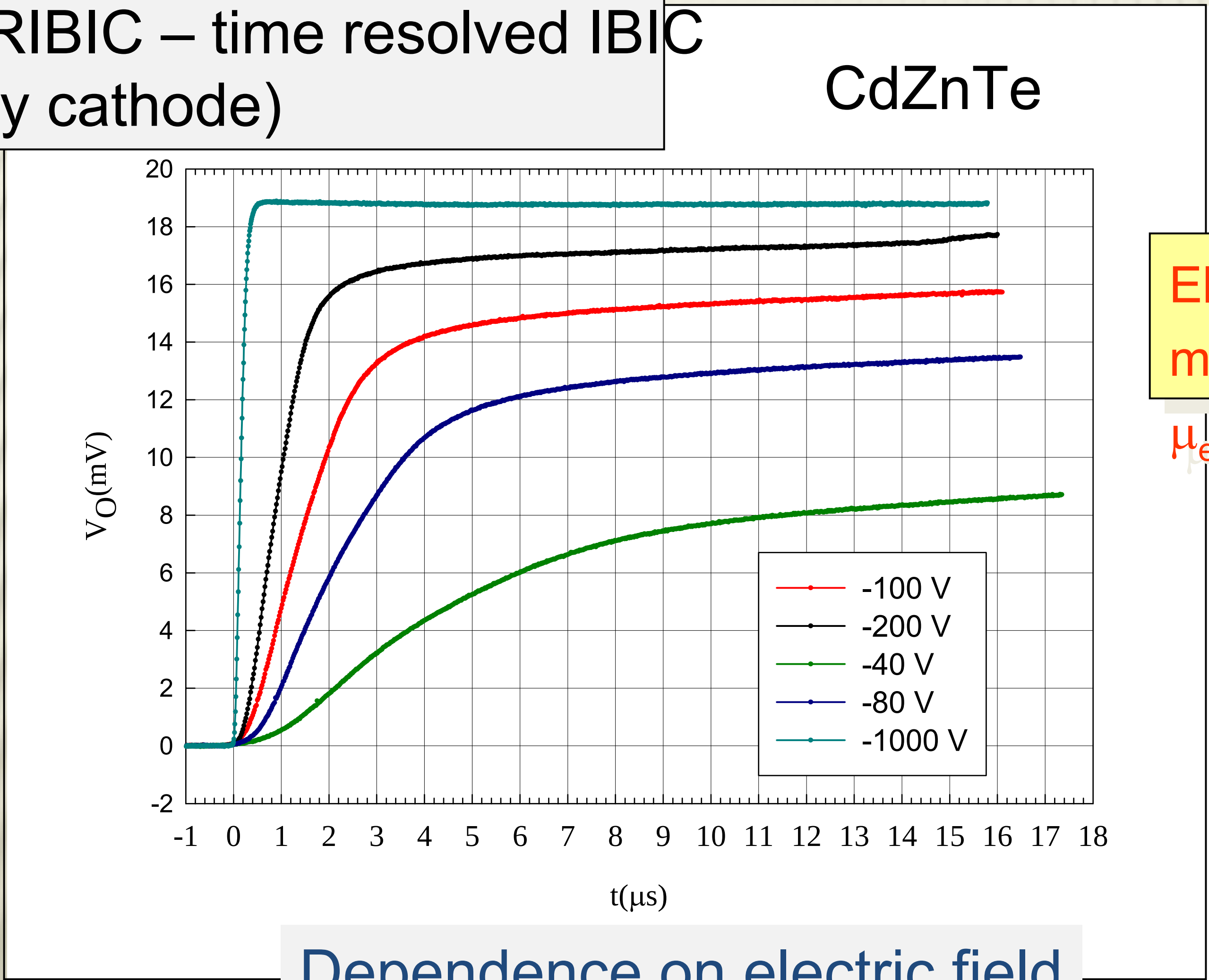
$$Q(t) = \int_0^T I(t)dt$$

$$I(t) = q \cdot \frac{v}{d} \cdot \exp\left[-\frac{t}{\tau}\right]$$



2. IBIC – ION BEAM INDUCED CHARGE

TRIBIC – time resolved IBIC (by cathode)



$$\mu = \frac{d^2}{t_r V}$$

Electron mobility:

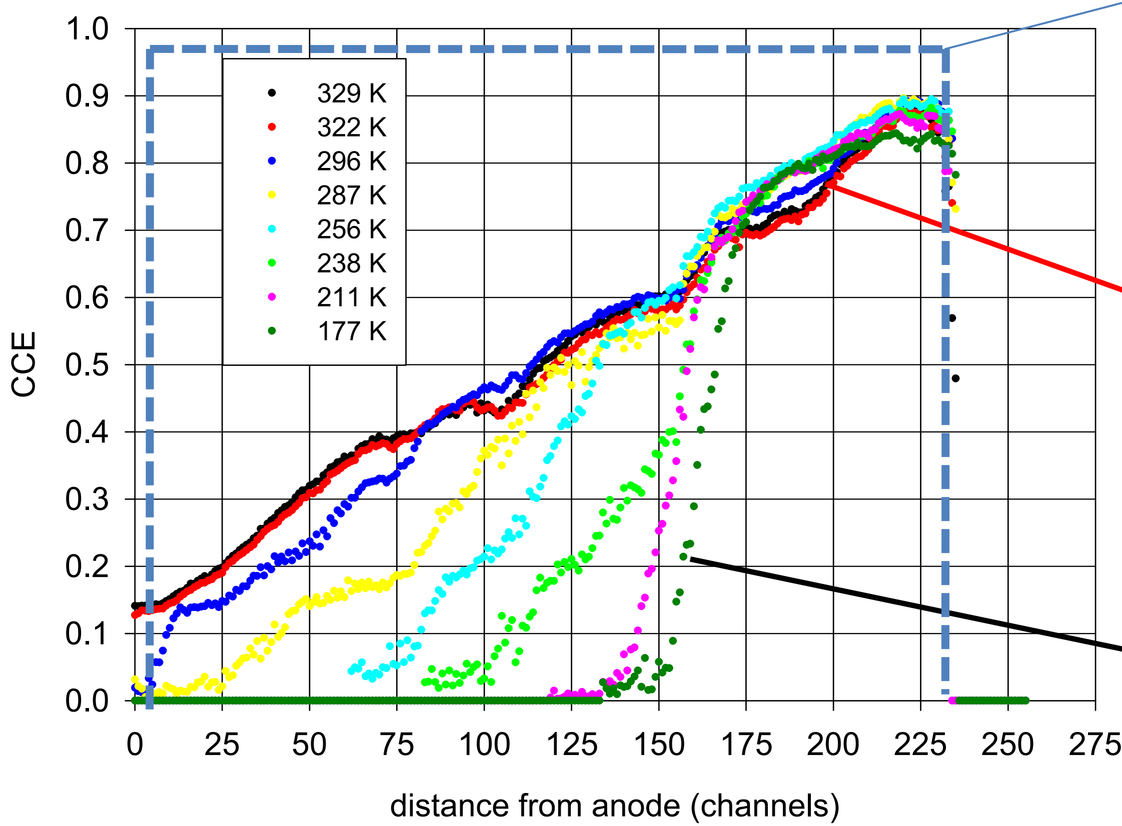
μ_e = 781 cm^2/Vs

Dependence on electric field → electron mobility

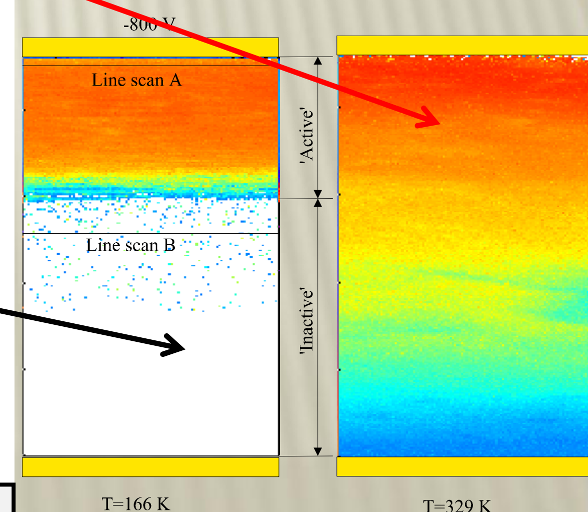
2. IBIC – ION BEAM INDUCED CHARGE

IBIC line scan (anode to cathode) CdZnTe

For CCE=100%



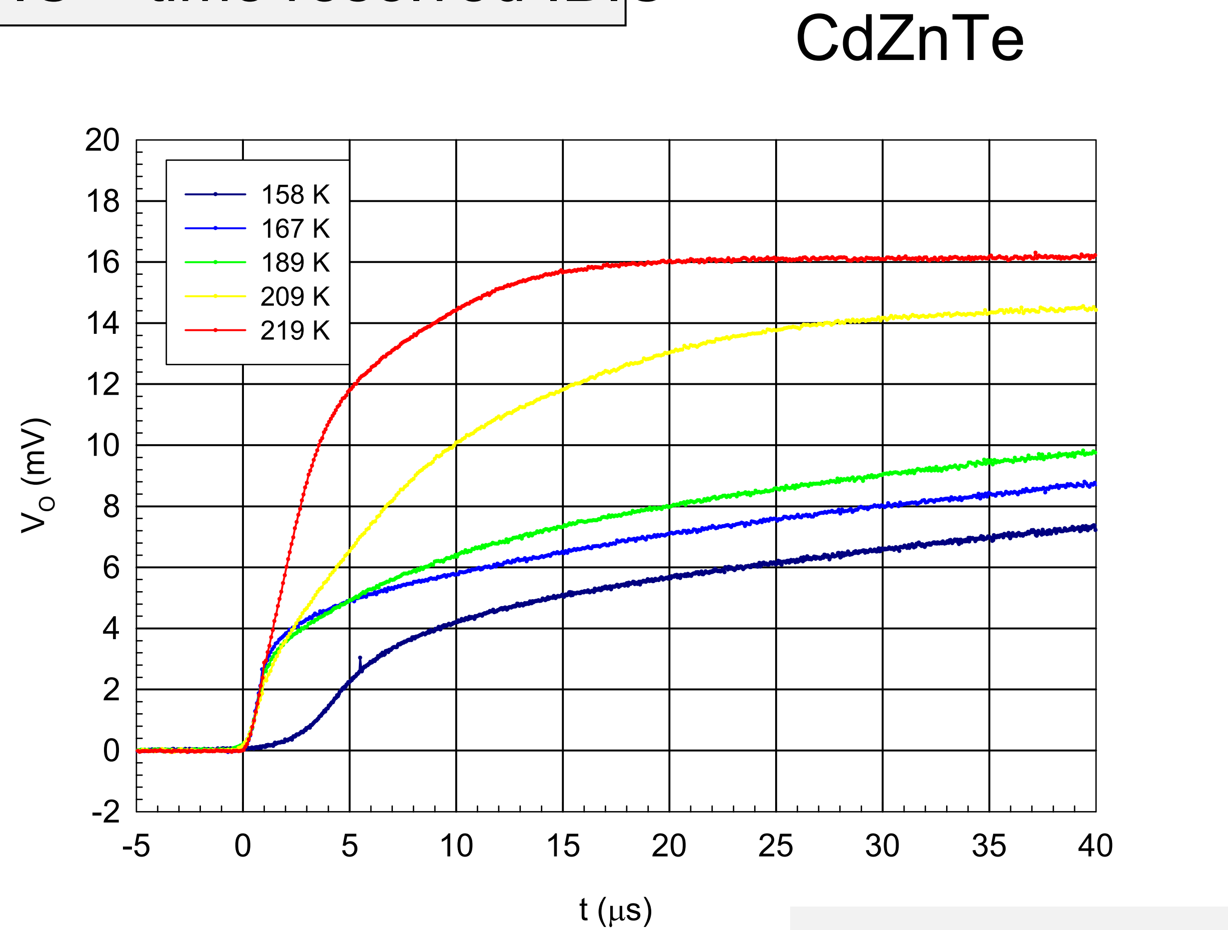
$(\mu\tau)_e=(1.4)*10^{-3}$ cm^2/V
$(\mu\tau)_h=1*10^{-5}$ cm^2/V



Dependence on temperature

2. IBIC – ION BEAM INDUCED CHARGE

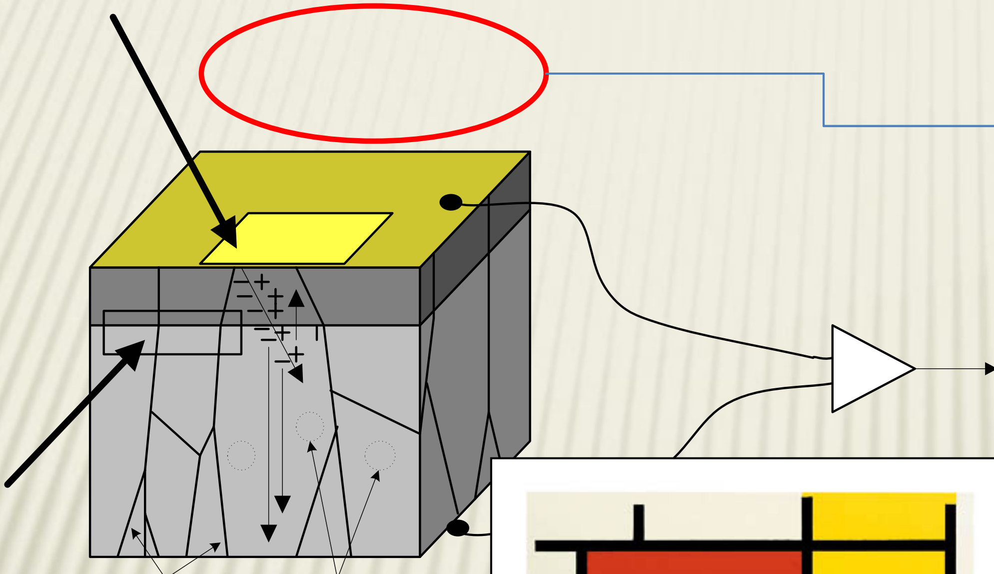
TRIBIC – time resolved IBIC

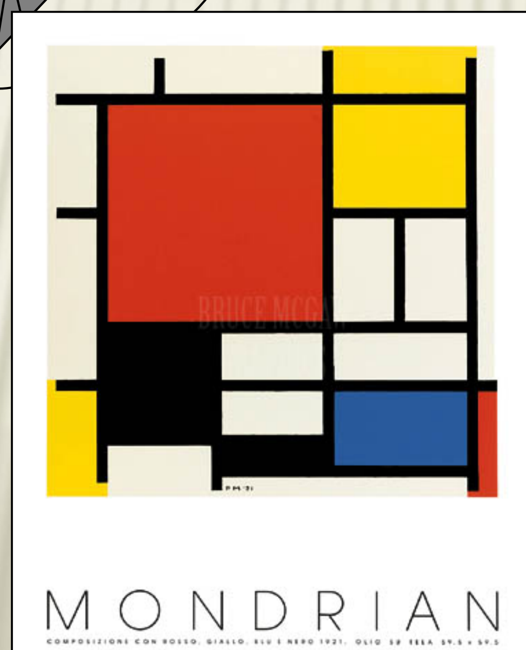


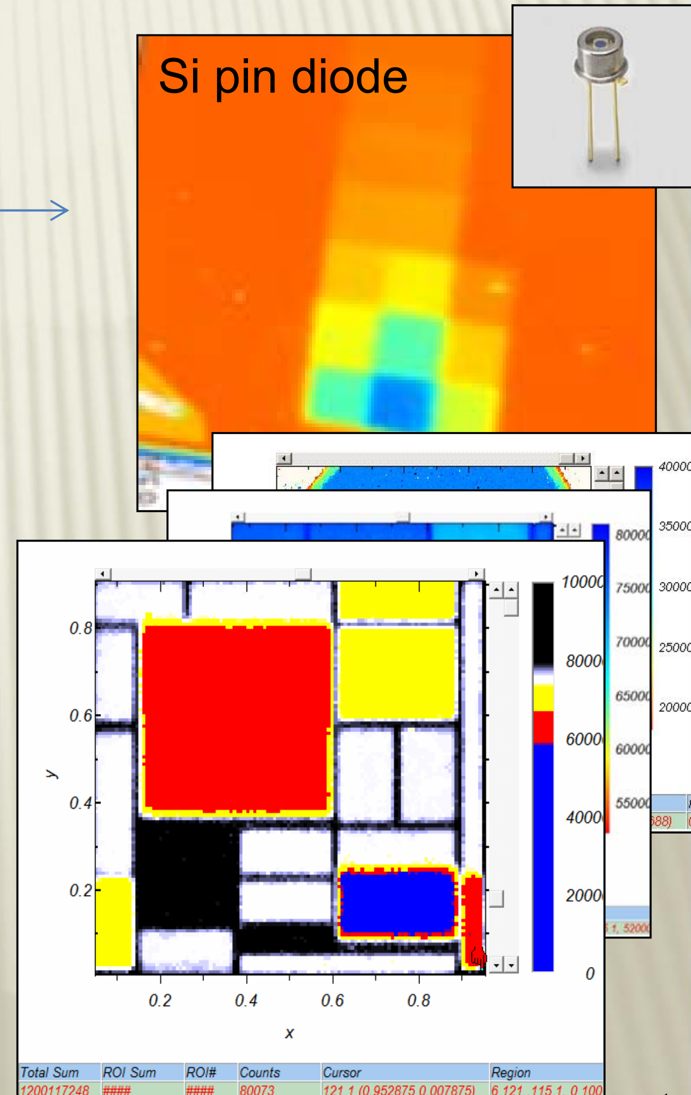
Dependence on temperature

3. ION BEAM INDUCED DEFECTS

MICROSTRUCTURING OF DEFECTS





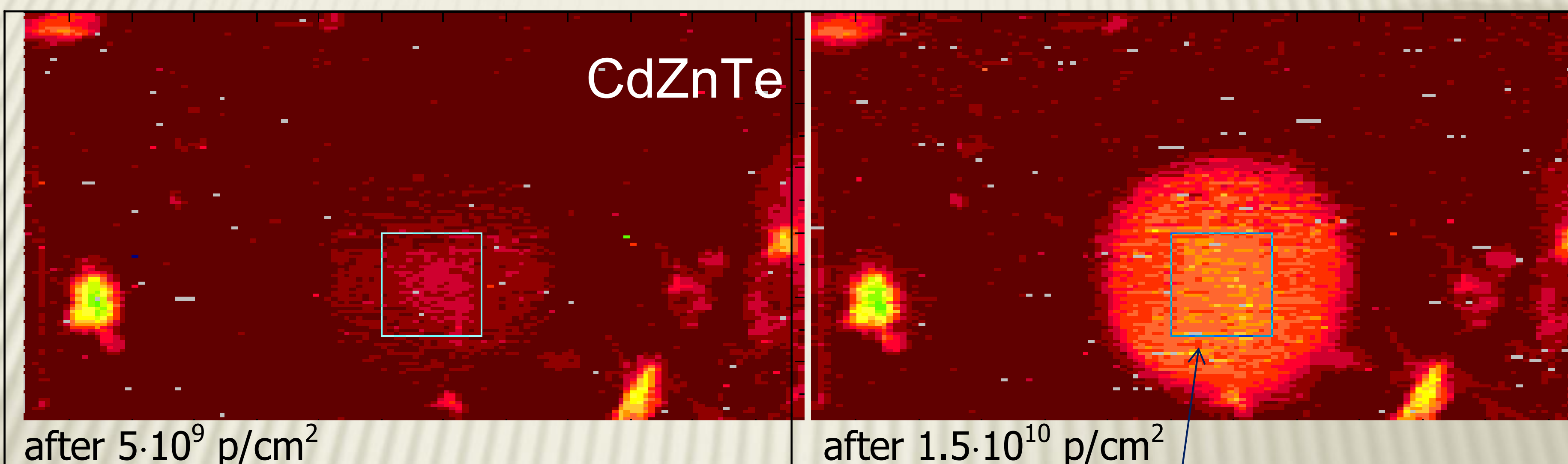


Irradiation of certain regions in test samples will increase defect concentration and decrease IBIC signal

Front

3. ION BEAM INDUCED DEFECTS

EVOLUTION OF DEFECT CONCENTRATION

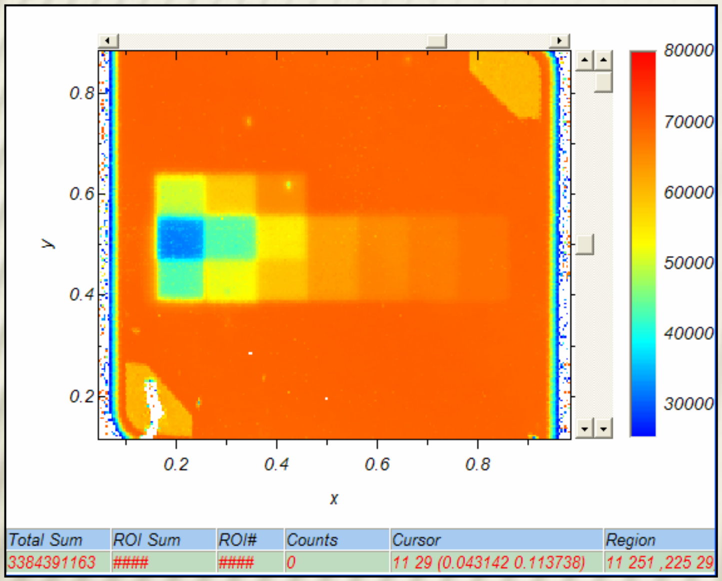


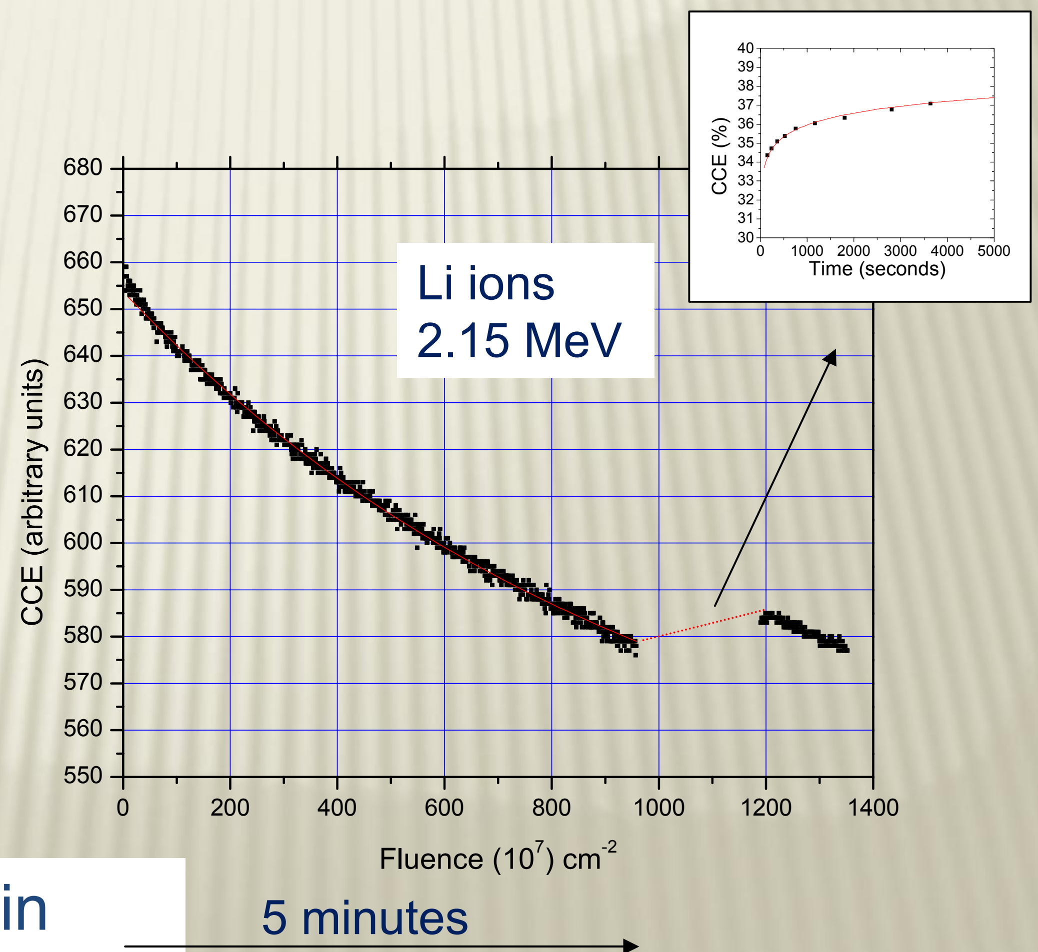
Mobility of defects (as in CdZnTe)

Irradiated area

3. ION BEAM INDUCED DEFECTS

EVOLUTION OF DEFECT CONCENTRATION

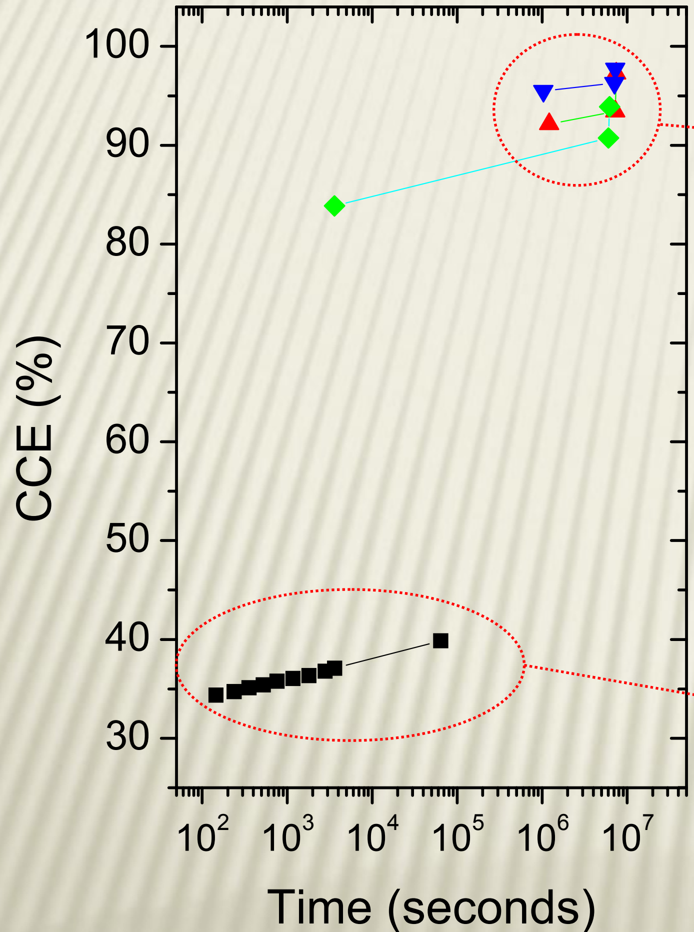


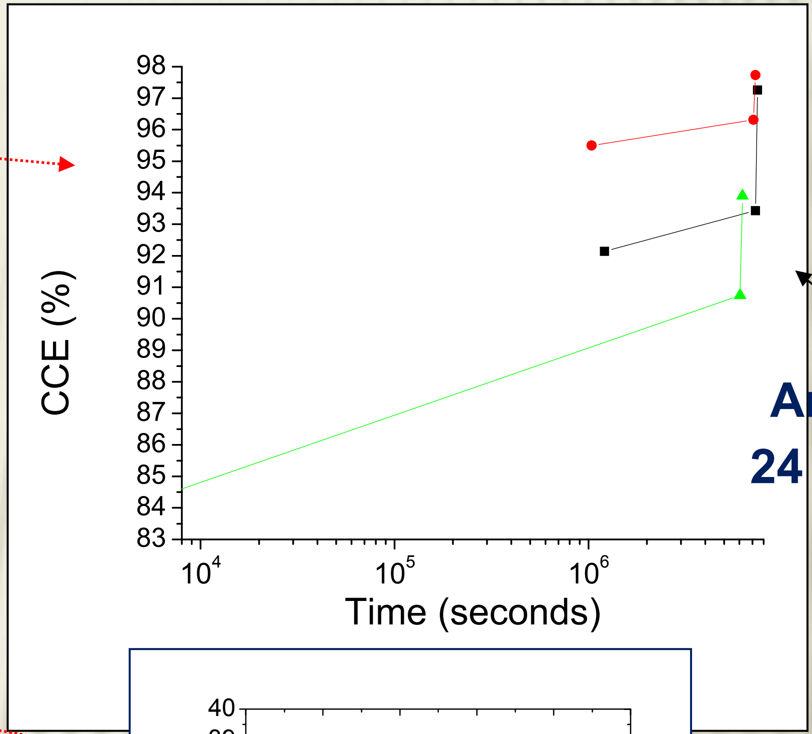


Recombination of defects in time

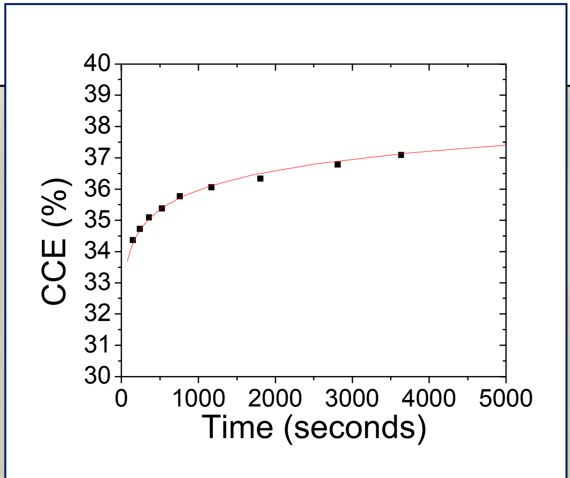
3. ION BEAM INDUCED DEFECTS

EVOLUTION OF DEFECT CONCENTRATION





Annealing 24 hours on 150⁰

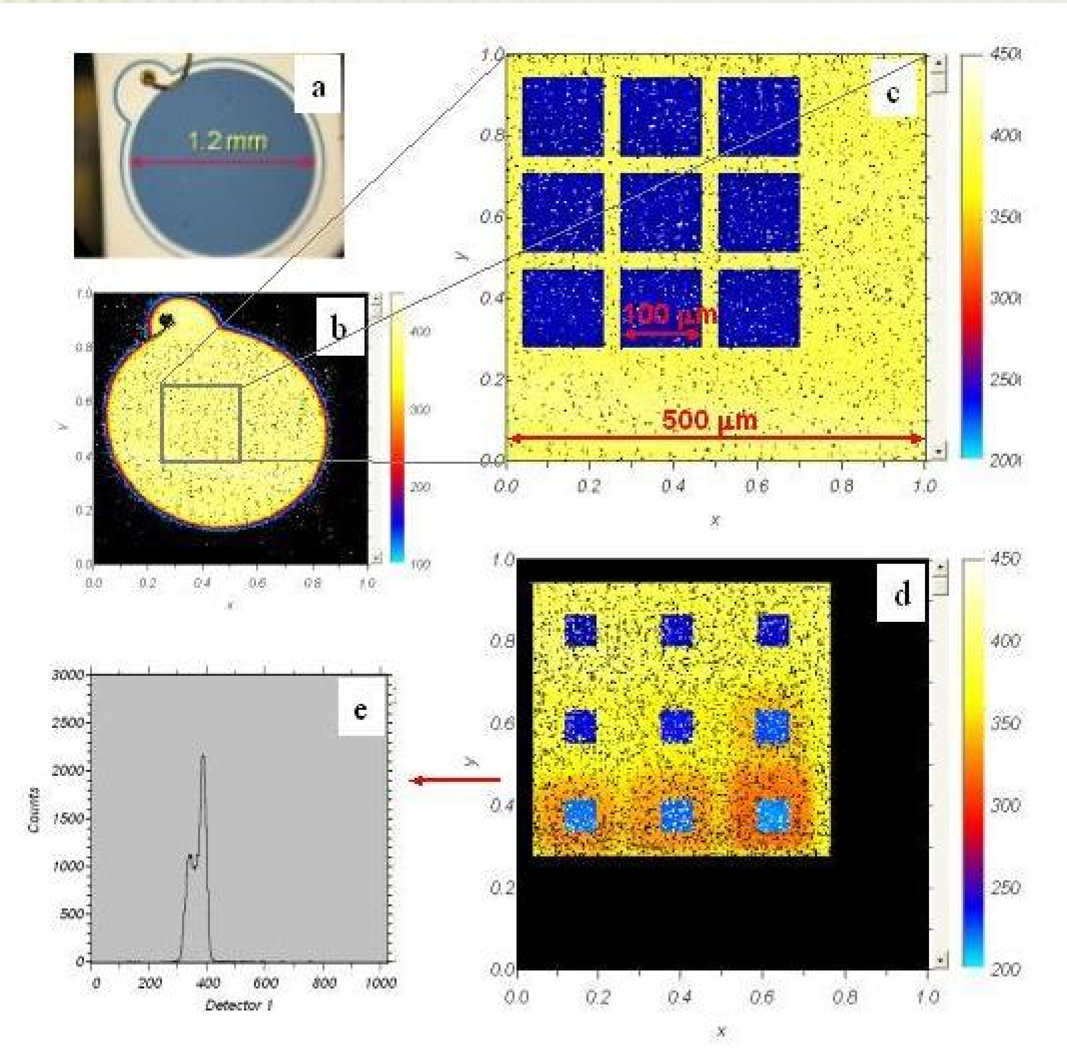


Measurements of recombination lifetimes!

Recombination of defects in time

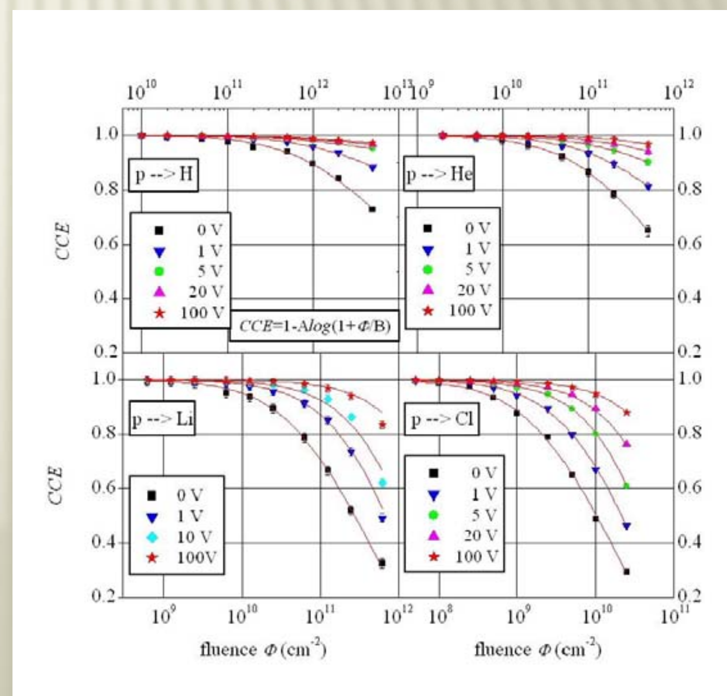
3. ION BEAM INDUCED DEFECTS

RADIATION HARDNESS TESTS - SILICON



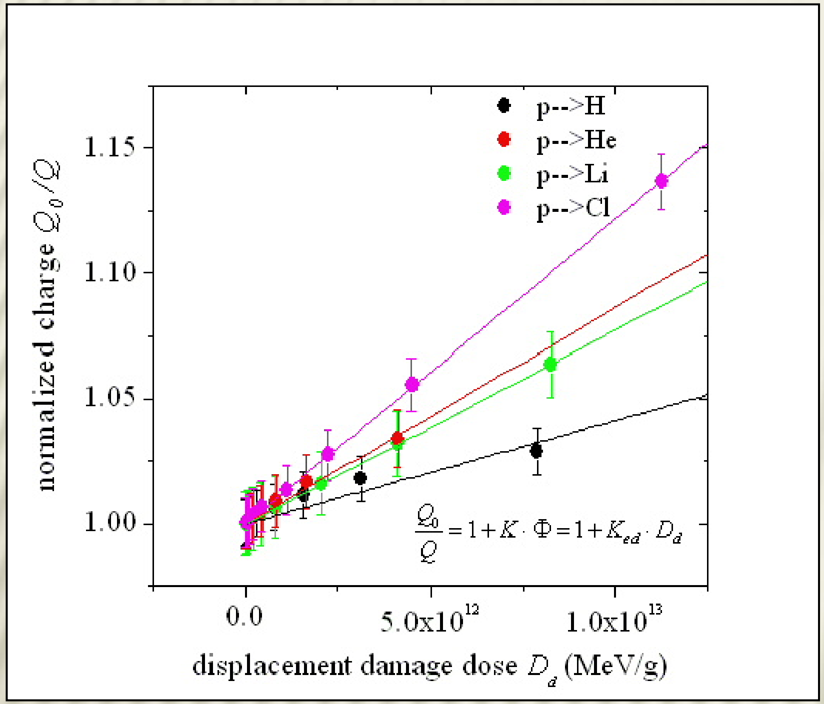
<u>Si PIN diode</u>

- irradiated by 9 fluences
- by p, He, Li, Cl of 5 um range
- tested by IBIC using protons



3. ION BEAM INDUCED DEFECTS

RADIATION HARDNESS TESTS - SILICON



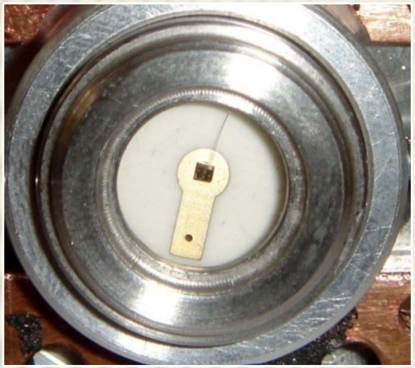
Si PIN diode
- irradiated by 9 fluences
- by p, He, Li, Cl of 5 um range
- tested by IBIC using p and He

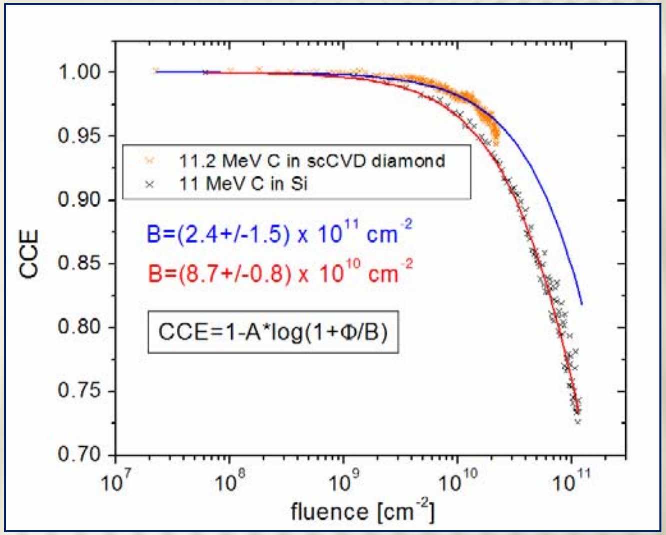
$$\frac{Q_0}{Q} = 1 + K_{ed} \cdot \Phi \cdot NIEL_{ave}$$

K_{ed} (g/MeV)	H impl.Si	He impl. Si	Li impl. Si	Cl impl. Si
H probe	$(4.1\pm0.4)\cdot10^{-15}$	$(8.6\pm0.3)\cdot10^{-15}$	$(7.7\pm0.1)\cdot10^{-15}$	$(1.22\pm0.01)\cdot10^{-14}$
He probe	no data	$(1.44\pm0.06)\cdot10^{-14}$	$(1.45\pm0.04)\cdot10^{-14}$	$(1.49\pm0.01)\cdot10^{-14}$

3. ION BEAM INDUCED DEFECTS

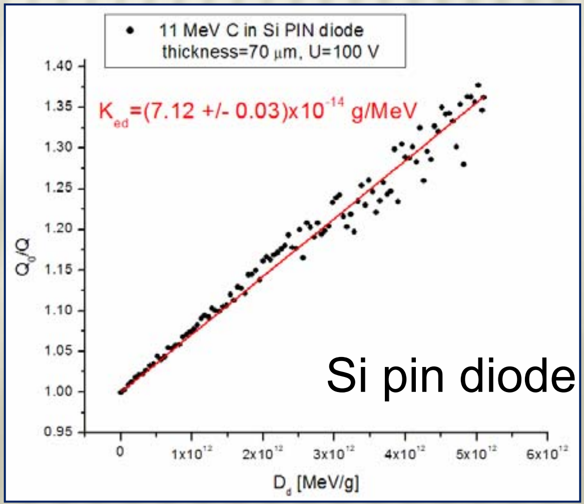
RADIATION HARDNESS TESTS – SC CVD DIAMOND

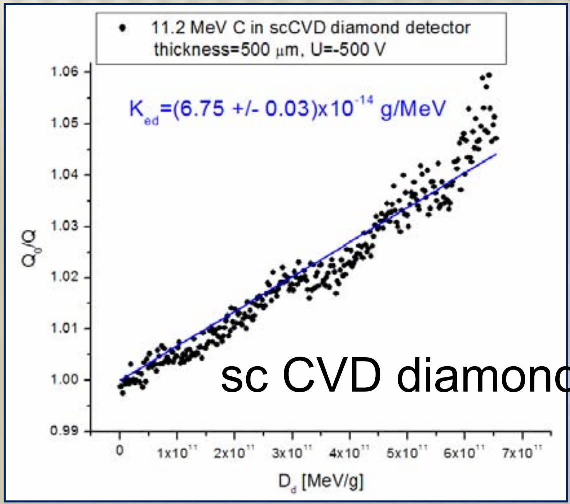




Diamond detectors
1 mm2, 500 um thick

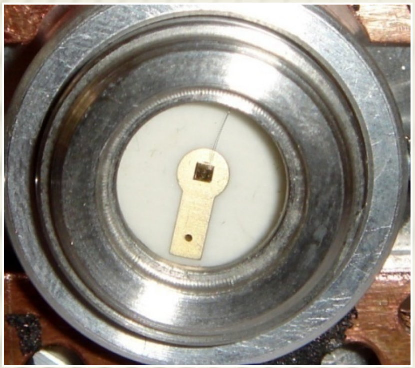
Irradiation and
IBIC tests by 11 MeV C ions

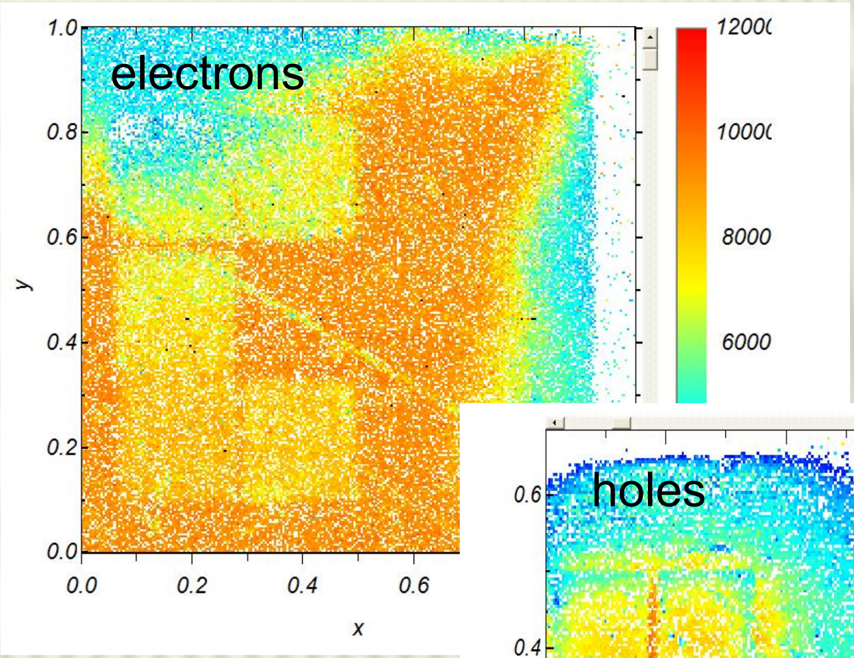


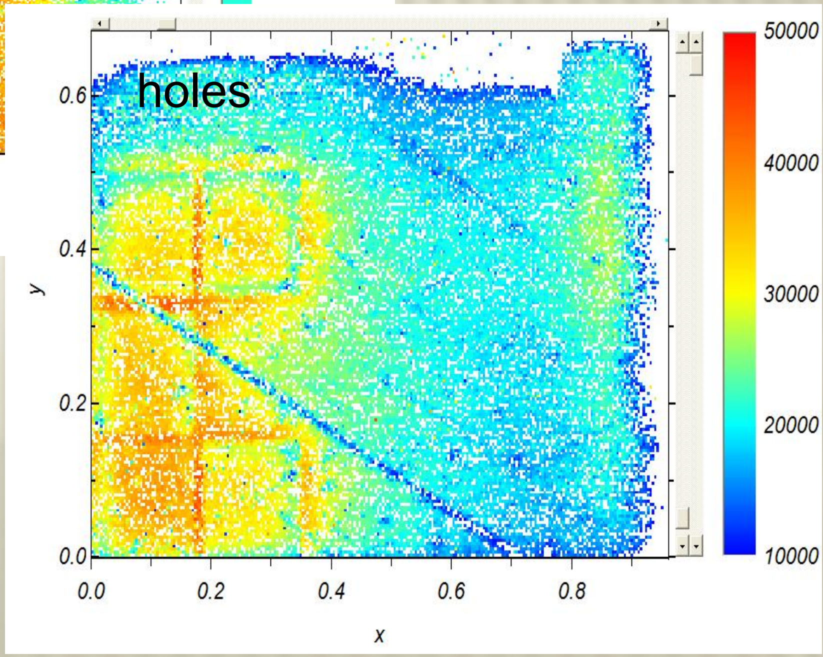


3. ION BEAM INDUCED DEFECTS

RADIATION HARDNESS TESTS – SC CVD DIAMOND







Diamond detectors
1 mm2, 500 um thick
+/- 500 V bias

Irradiation and
IBIC tests by 8 MeV C ions

EU - FP7 NETWORK SPIRIT

Support of Public and Industrial Research using Ion beam Technology

- Transnational access
- Networking
- Joint research activities

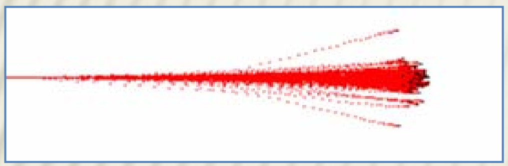
SPIRIT Partners:

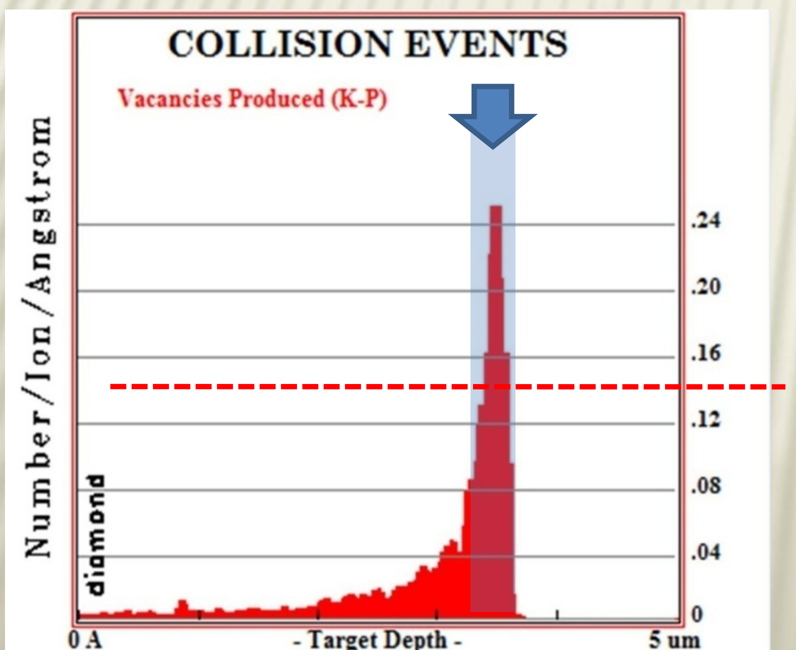
- ForschungszentrumDresden-Rossendorf (FZD)
- CNRS –CENBG Bordeaux (CNRS)
- Katholieke Universiteit Leuven + IMEC (KUL)
- Jozef Stefan Institut Ljubljana (JSI)
- Universität der Bundeswehr München + TUM (UBW)
- CEA –JANNUS Saclay and CIMAP Caen (CEA)
- University of Surrey (SUR)
- Institute Tecnologico e Nuclear Lisboa (ITN)
- University de Pierre et Marie Curie (UPMC)
- Rudjer Boskovic Institute Zagreb (RBI)
- Swiss Federal Institute of Technology (ETHZ)

ION BEAM MODIFICATION

CONDUCTIVE LINES IN DIAMOND

Damage profile of 6 MeV C ions in diamond (SRIM simulation)





✓if the diamond lattice gets damaged / distorted above a critical threshold, it converts to graphite upon thermal annealing

✓graphite is a <u>very different</u> material with respect to diamond: it is soft, **electrically conductive** and **etchable**

damage density threshold

$< 9{\cdot}10^{22}$ cm^{-3} → (partial) recovery of pristine structure upon thermal annealing

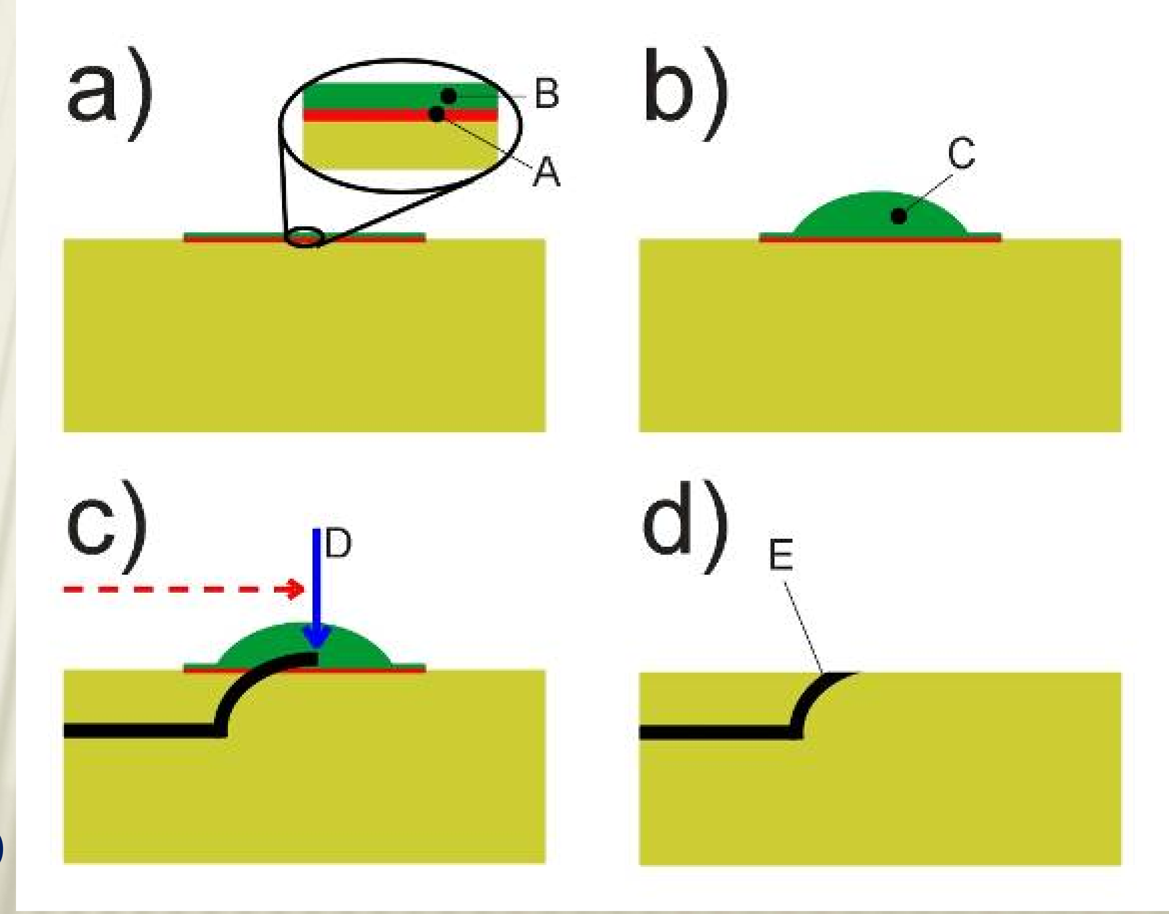
$> 9{\cdot}10^{22}$ cm^{-3} → conversion to a <u>graphite-like phase</u> upon thermal annealing

ION BEAM MODIFICATION

CONDUCTIVE LINES IN DIAMOND

- evaporation of Cr-Au adhesion layer
- deposition of semi-spherical Au contact mask
- implantation with scanning ion microbeam
- mask removal

Implantation with three-dimensional masking

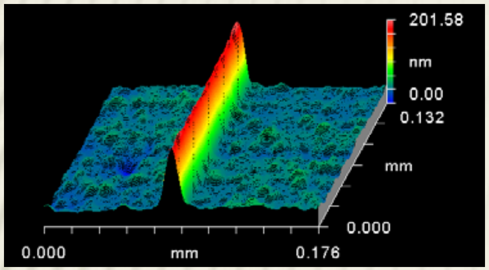


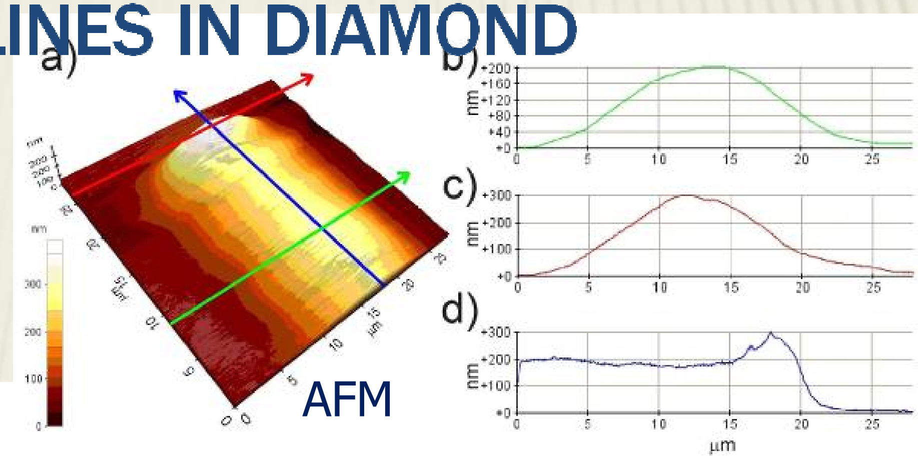
A: Cr layer
B: Au layer
C: Au contact mask
D: scanning ion beam (6 MeV C)
E: buried graphitic channel

P. Olivero et al, Diamond Rel. Mat. (2008)

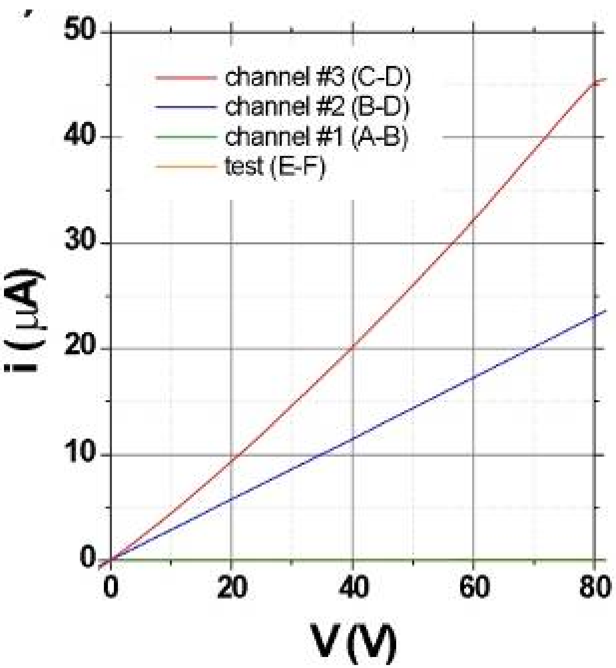
ION BEAM MODIFICATION

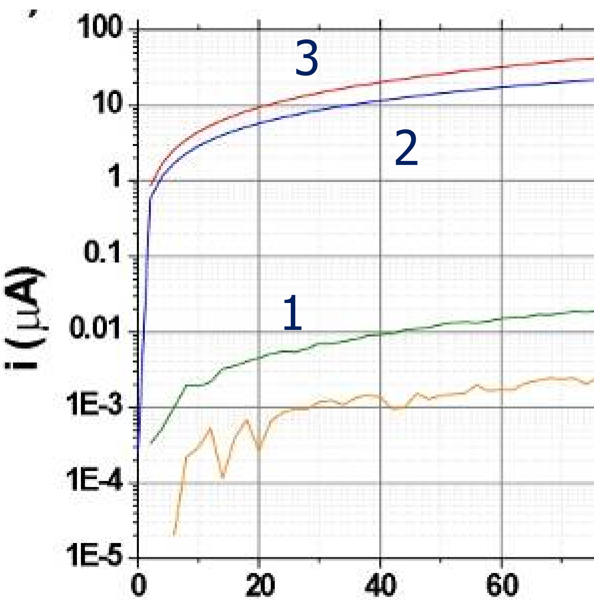
CONDUCTIVE LINES IN DIAMOND

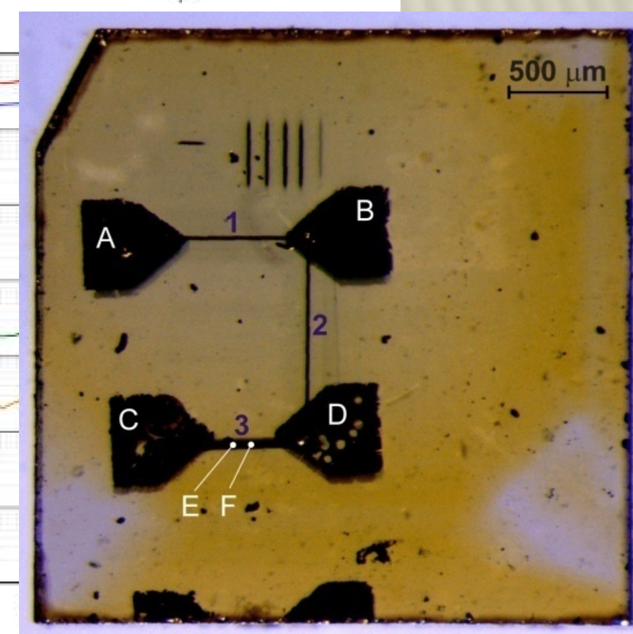




Electrical characterisation:







R = 3.5, 1.5 MΩ channels
2&3 + geometry → ρ = 0.9, 1.1 Ω cm