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Angle Resolved Differential IBIC analysis of silicon power diodes

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RADIATE

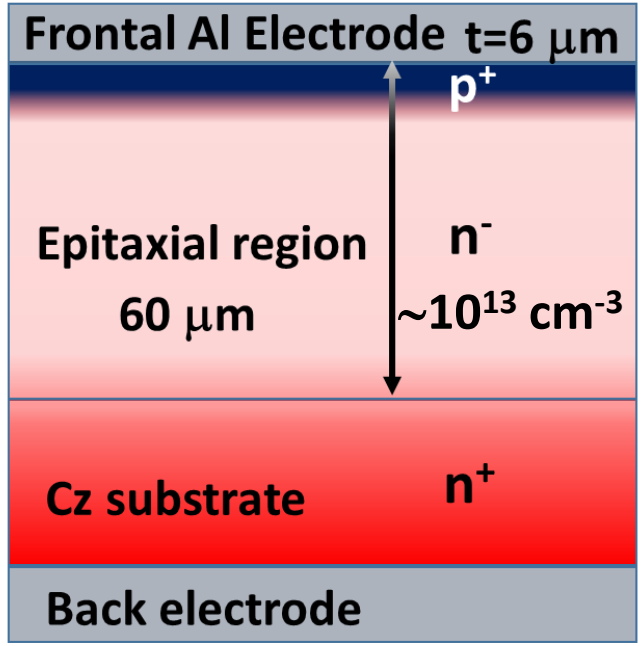
Proposal No.: 20002020-ST for IBIC (@RBI)

Objective:

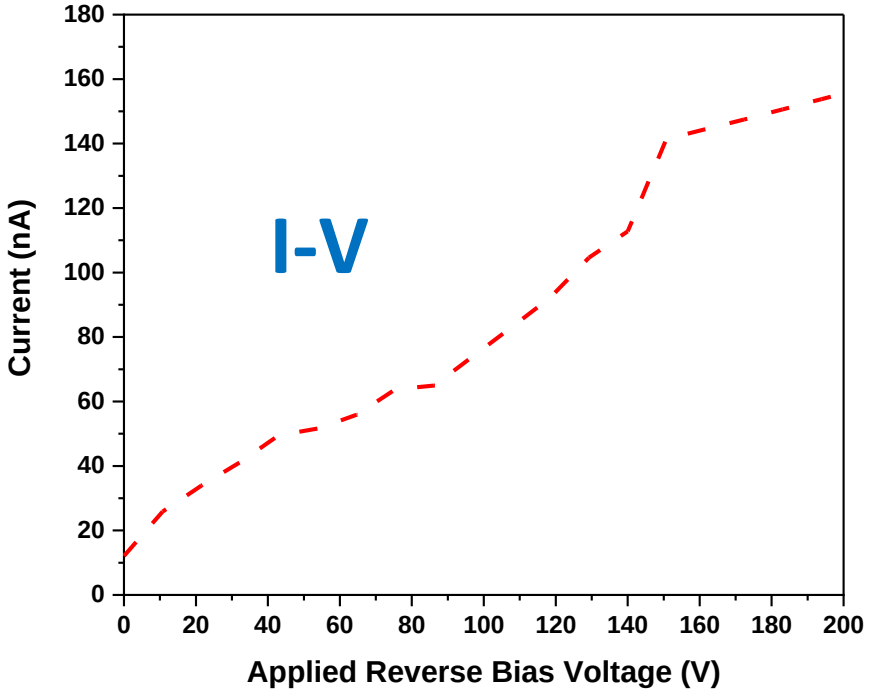
- **Electronic characterization of power diodes**

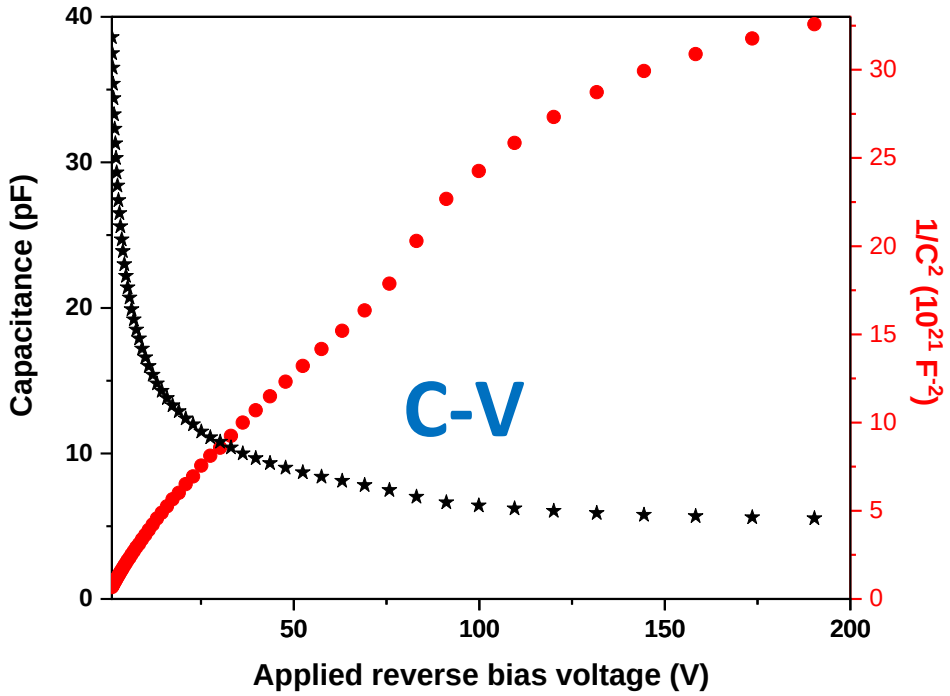
What: object of study

- **Commercially available p-i-n power diode**



Electrical characterization



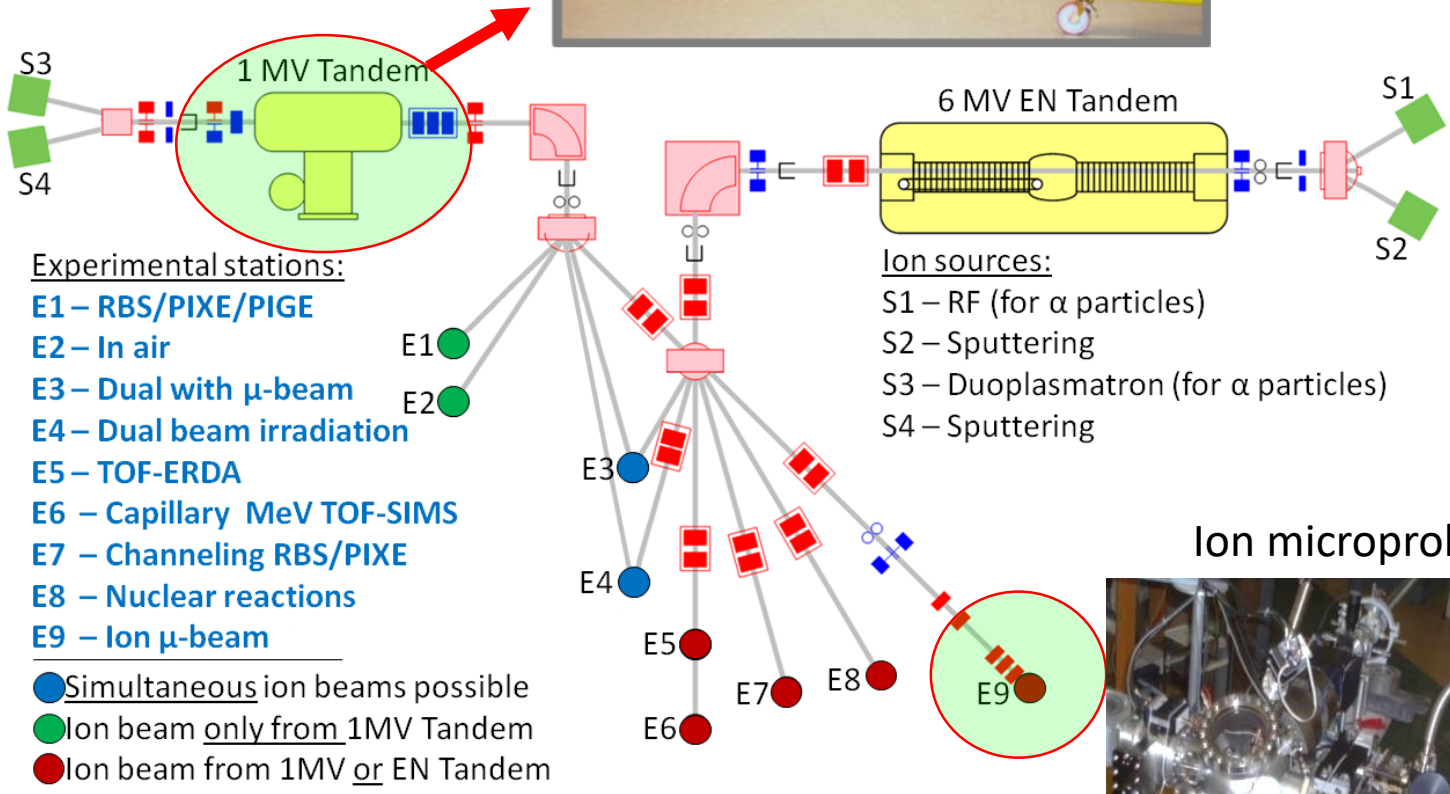


Where:

Institut Ruđer Bošković

The experiments were performed at the Laboratory for Ion Beam Interactions of the Ruder Boskovic Institute in Zagreb (HR) at the **ion microbeam line** coupled to the **1.0 MeV Tandetron accelerator**

Proton microbeams 1.2, 1.5, 1.7, 2.0 MeV
Spot size < 5 μm

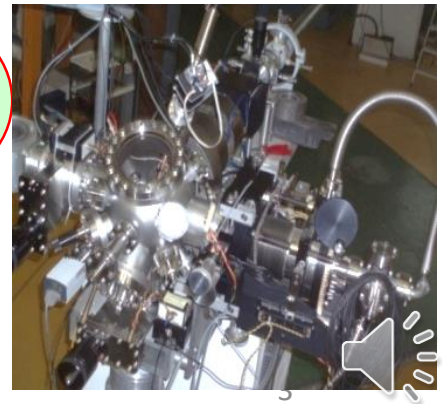


Experimental stations:
E1 – RBS/PIXE/PIGE
E2 – In air
E3 – Dual with μ-beam
E4 – Dual beam irradiation
E5 – TOF-ERDA
E6 – Capillary MeV TOF-SIMS
E7 – Channeling RBS/PIXE
E8 – Nuclear reactions
E9 – Ion μ-beam

Simultaneous ion beams possible
Ion beam only from 1MV Tandem
Ion beam from 1MV or EN Tandem

Ion sources:
S1 – RF (for α particles)
S2 – Sputtering
S3 – Duoplasmatron (for α particles)
S4 – Sputtering

Ion microprobe

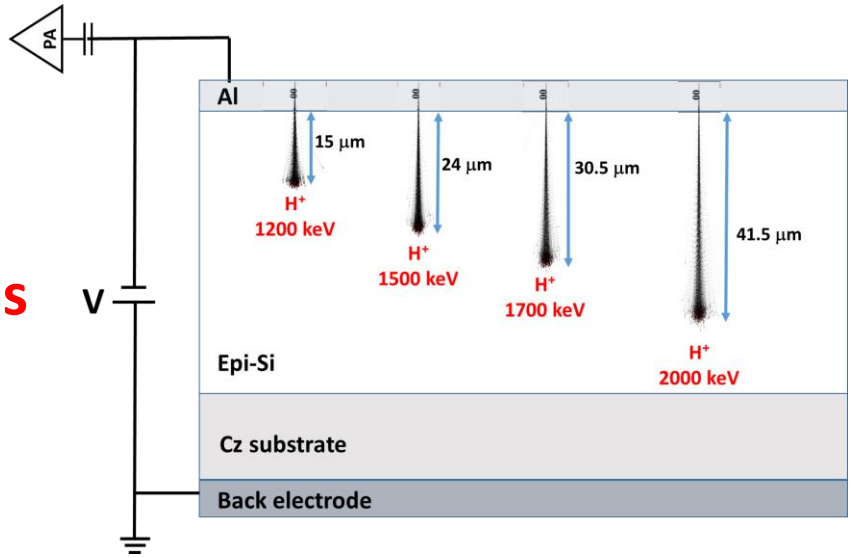


https://www.irb.hr/eng/Divisions/Division-of-Experimental-Physics/Laboratory-for-ion-beam-interactions

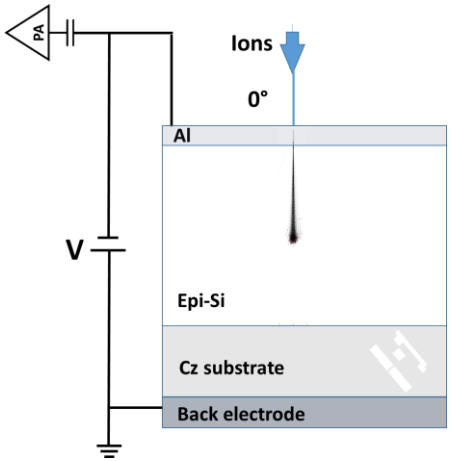
How: Polychromatic angle resolved IBIC analysis

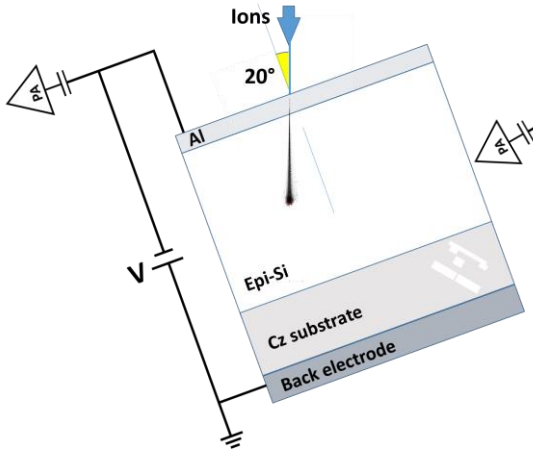
Modulation of the probing depth by

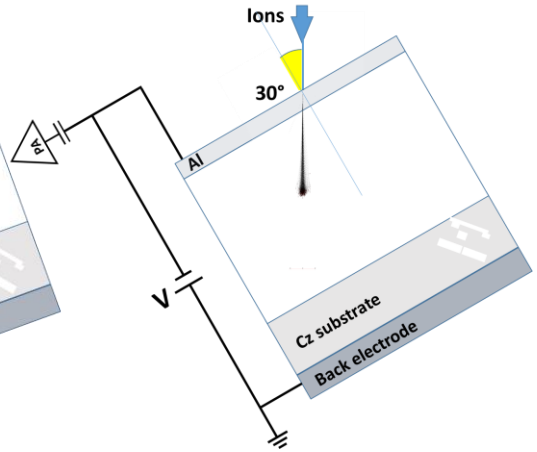
Using different proton energies

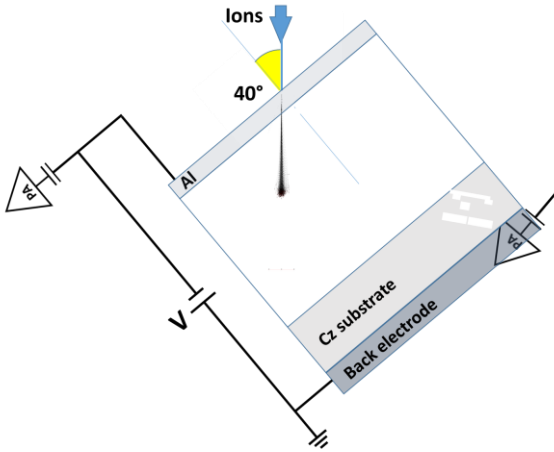


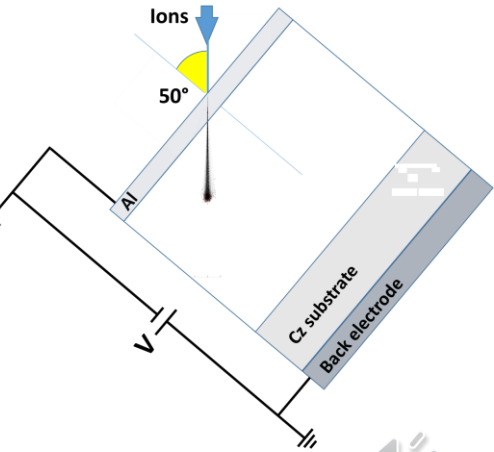
Tilting the sample with respect to the proton beam axis at different angles





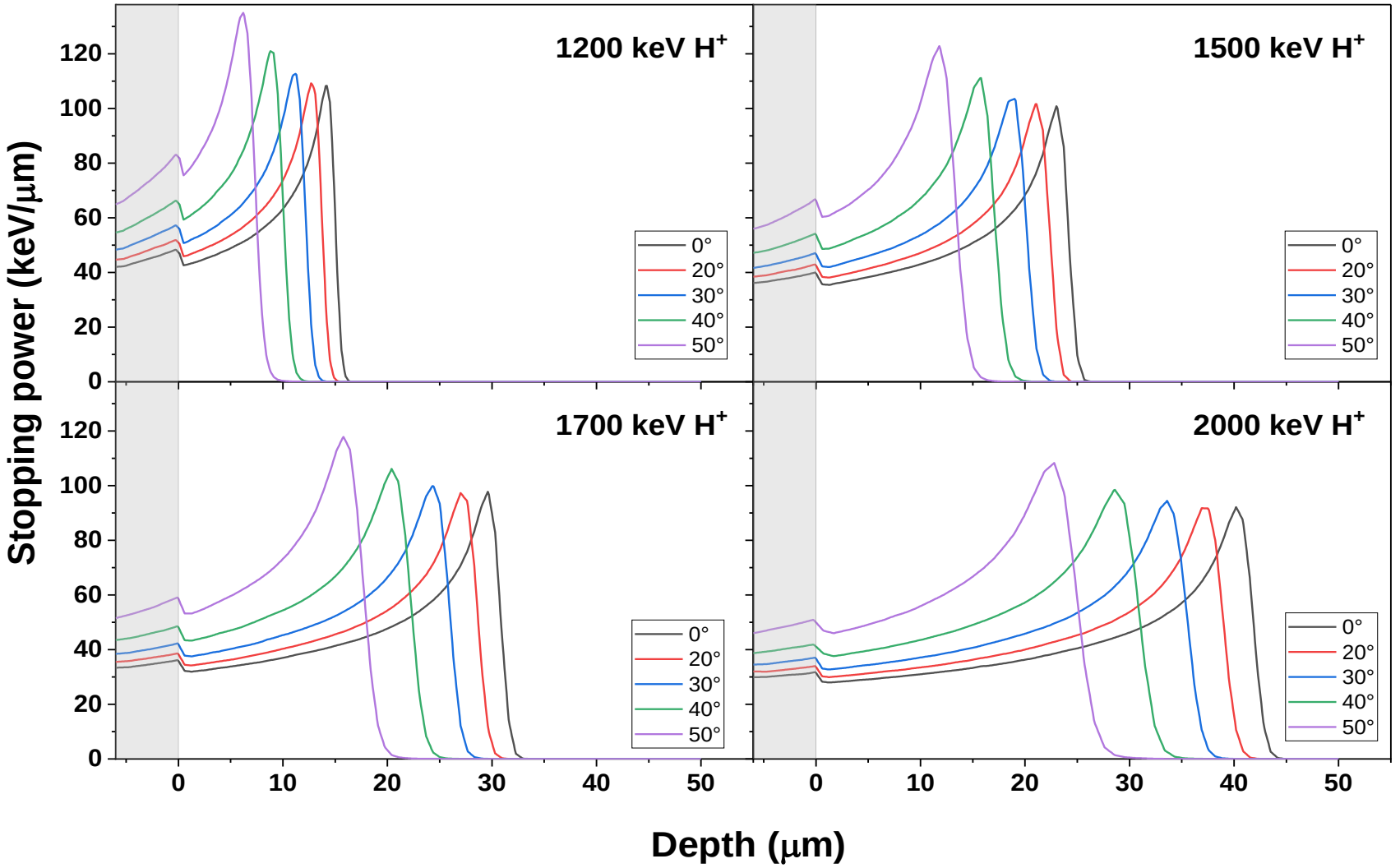






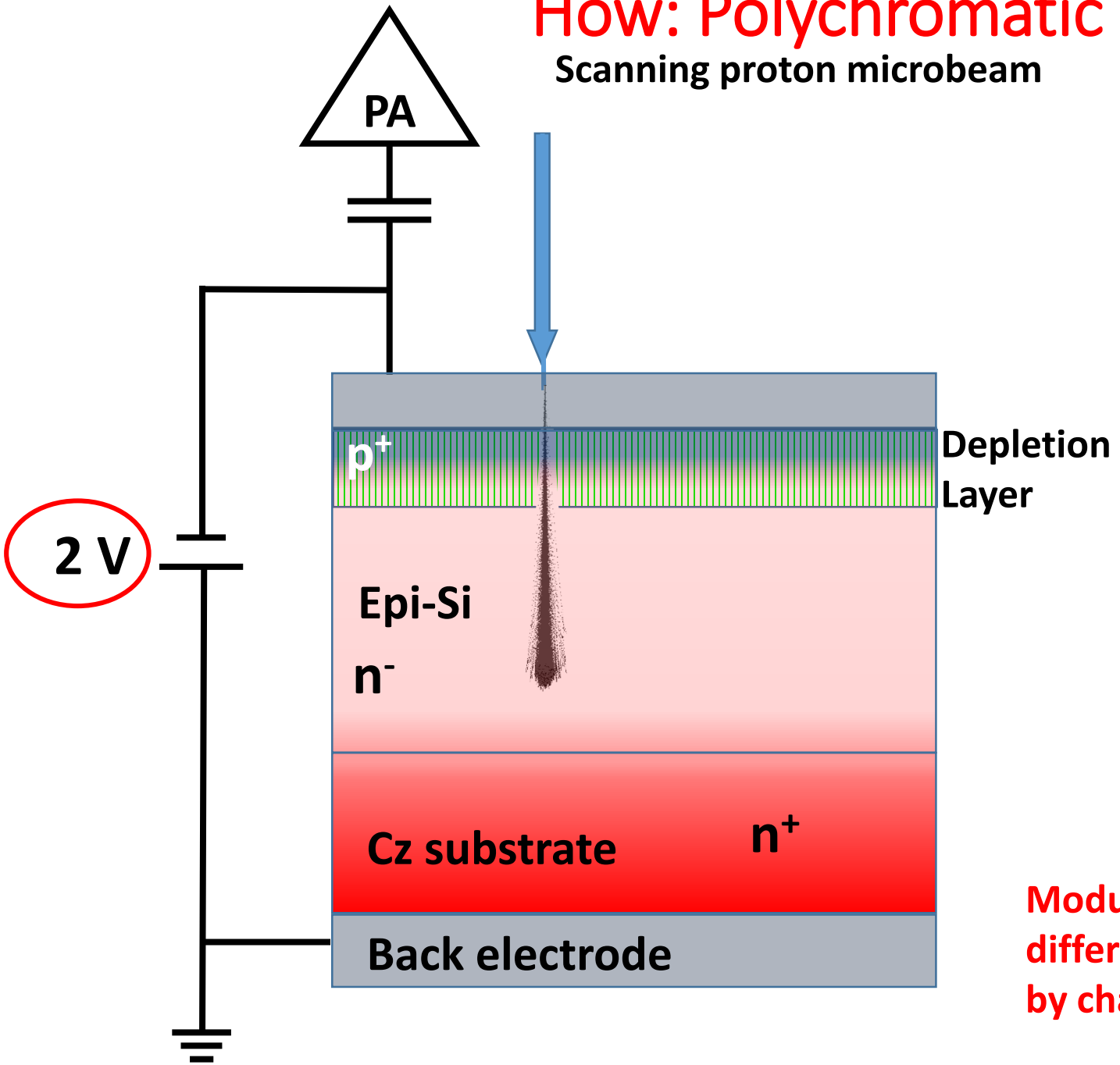
How: Polychromatic angle resolved IBIC analysis

Modulation of the carrier generation profiles by different tilting angle and different ion energies

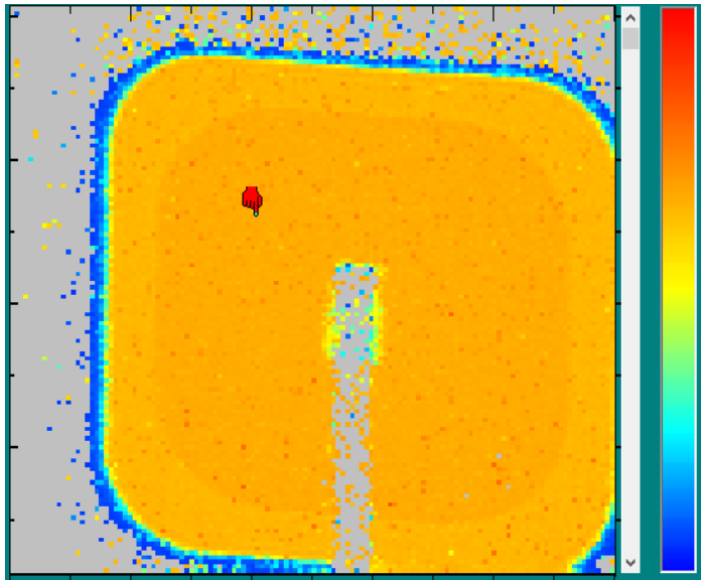


How: Polychromatic angle resolved IBIC analysis

Scanning proton microbeam



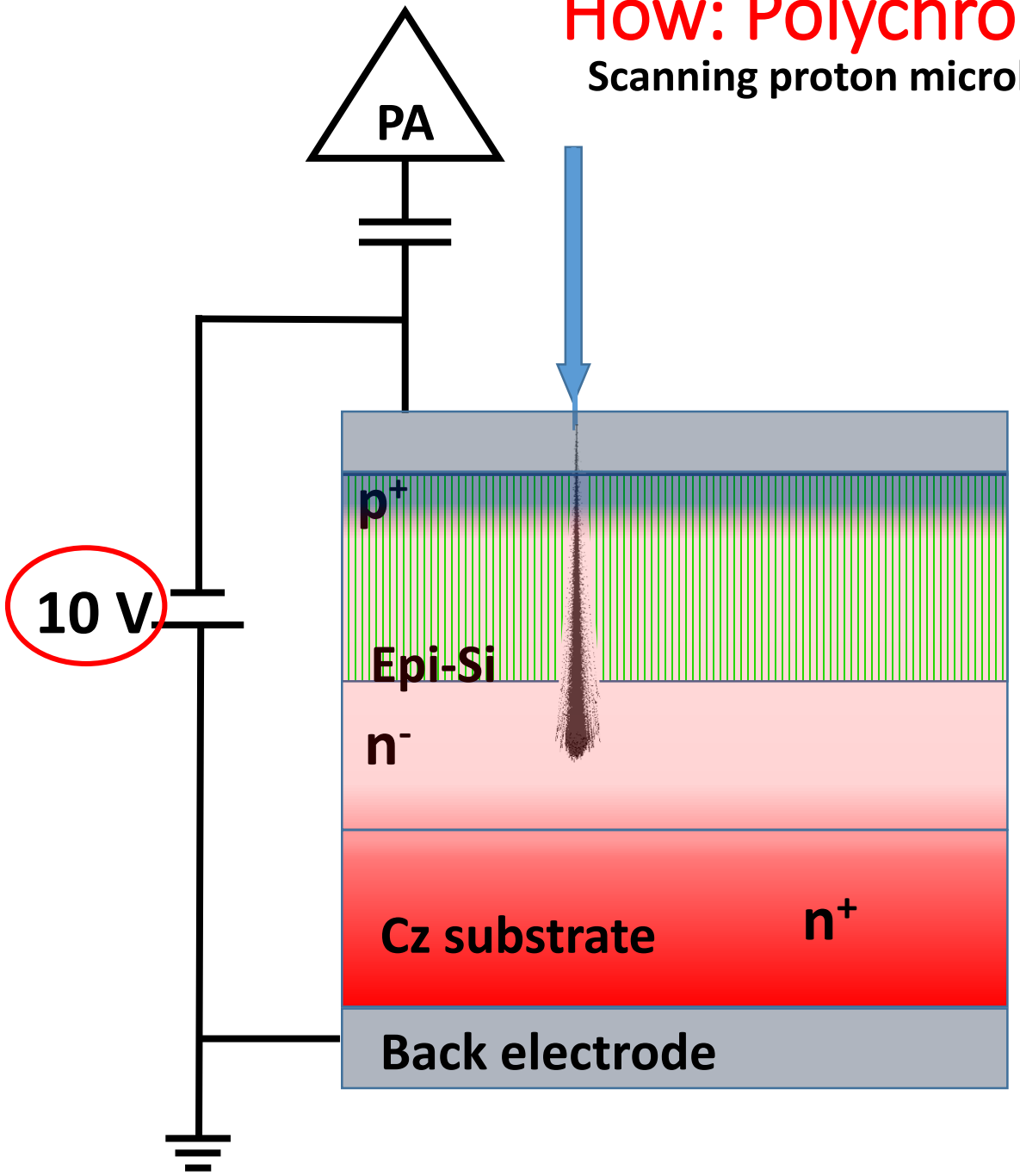
IBIC Map
1.7 MeV proton
Applied Bias = 2 V



Modulation of the carrier generation profiles by different widths of the depletion region induced by changing the applied bias voltage

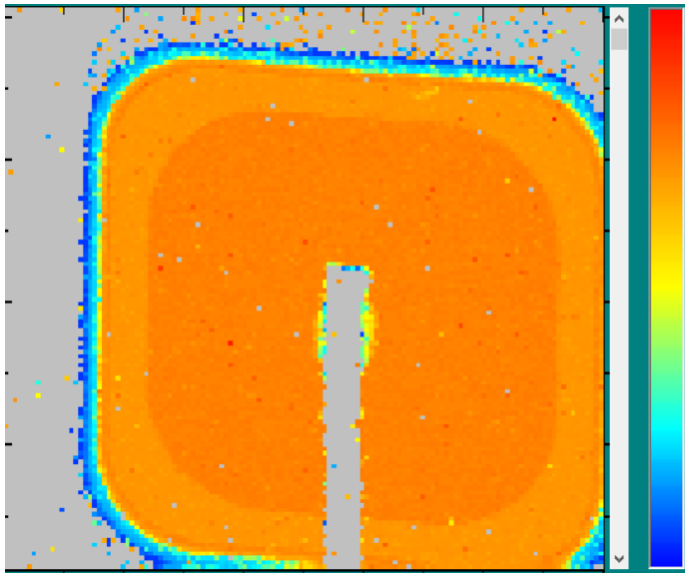
How: Polychromatic angle resolved IBIC analysis

Scanning proton microbeam



Depletion Layer

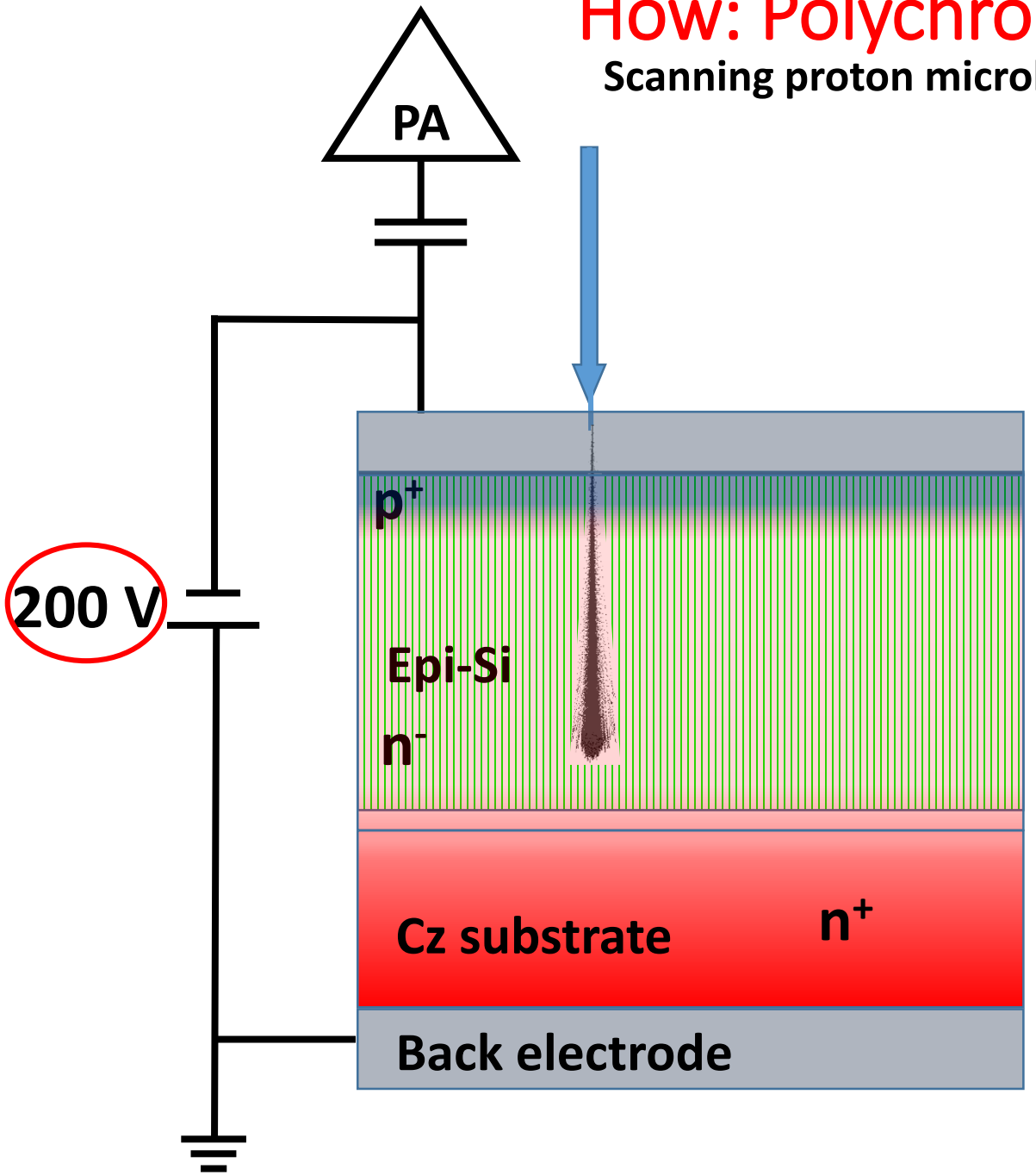
IBIC Map
1.7 MeV proton
Applied Bias = 10 V



Modulation of the carrier generation profiles by different widths of the depletion region induced by changing the applied bias voltage

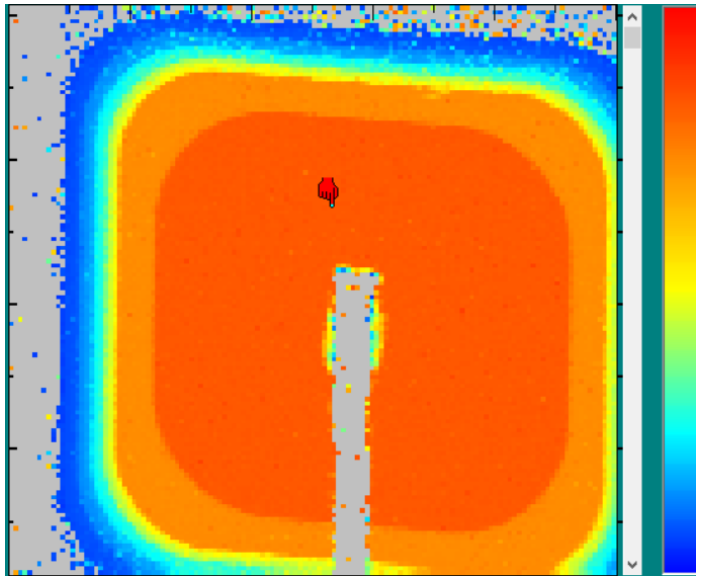
How: Polychromatic angle resolved IBIC analysis

Scanning proton microbeam



Depletion Layer

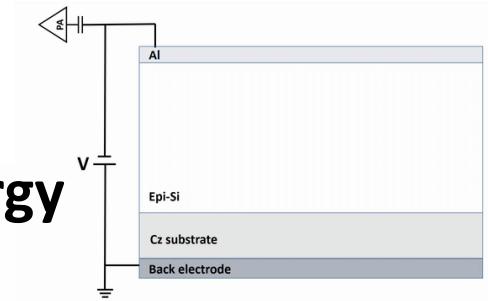
IBIC Map
1.7 MeV proton
Applied Bias = 200 V



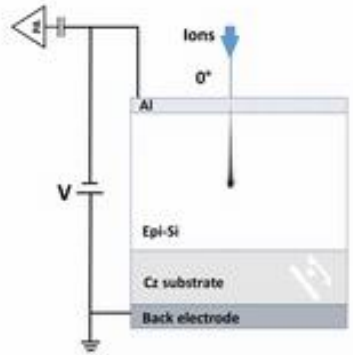
Modulation of the carrier generation profiles by different widths of the depletion region induced by changing the applied bias voltage

Parameter space: (E,θ,V)

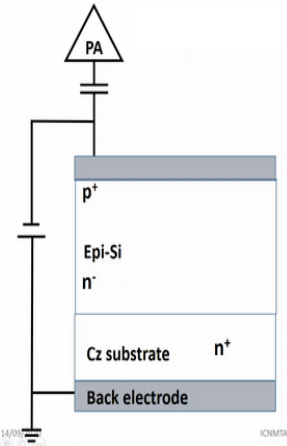
E
ion energy



θ
Tilting angle



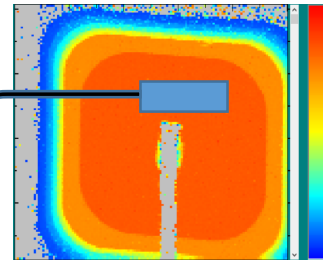
V
Bias voltage



14/09/2020

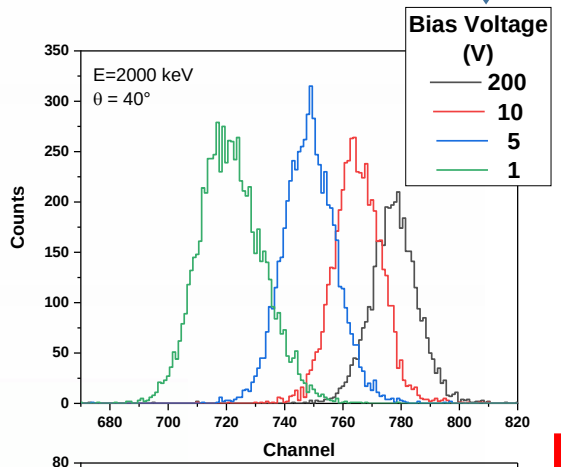
For each (E)

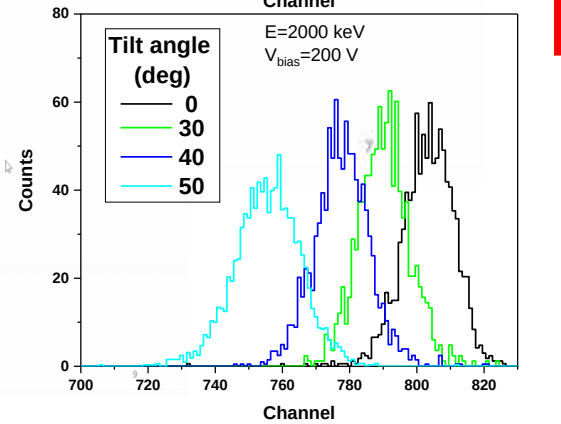
IBIC Map

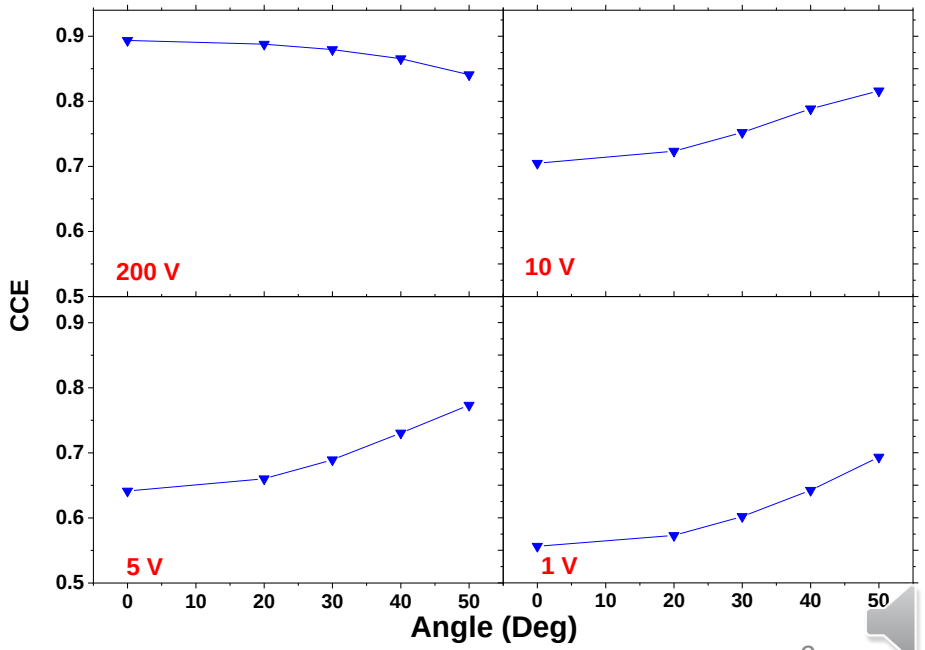


Selecting a region

IBIC SPECTRA



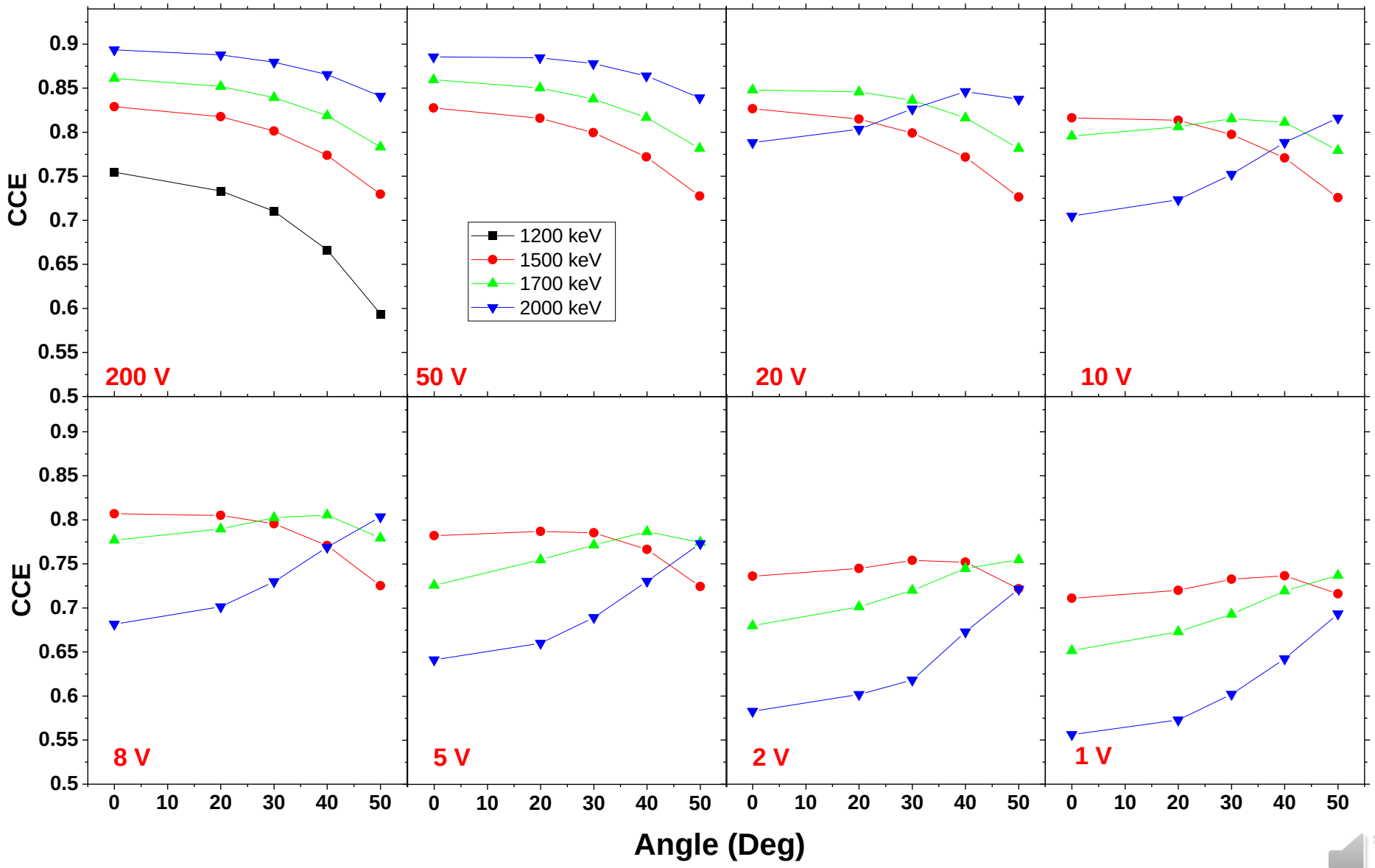




Experimental Results: Charge Collection Efficiency (CCE)

Experimental CCE as function of Tilting angle θ @ different V Parametrized by E

Lines are interpolating segments as a guide for the eyes



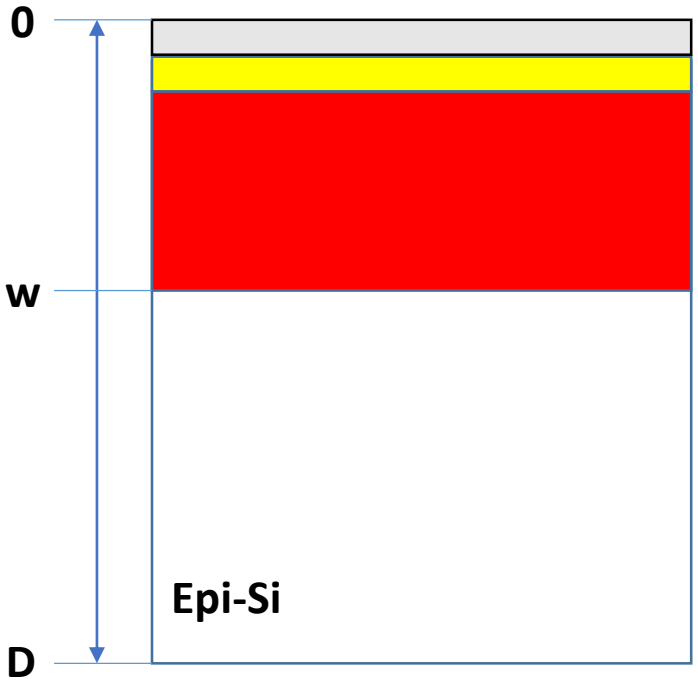
Model based on simplified IBIC theory

$$\mathbf{CCE_{model}(\theta, E_{Ion}, V)} = \int_0^D \eta(x) \cdot \left[\frac{dE}{dx}\right]_{\theta, E_{Ion}} dx$$

CCE profile

Generation profile
Electron stopping power

Best fit with two free parameters:
W(V): depletion layer width as function ov V
Lh: minority carrier diffusion length



Al Electrode+Si Dead layer: η(x)=0

Depletion region: η(x)=1

Neutral region: $\eta(x)=\frac{\cosh(D-x)}{\cosh(D-w)}$ Solution of $\frac{d^2\eta(x)}{dx^2}=\frac{\eta(x)}{{L_h}^2}$

With bounday conditions:

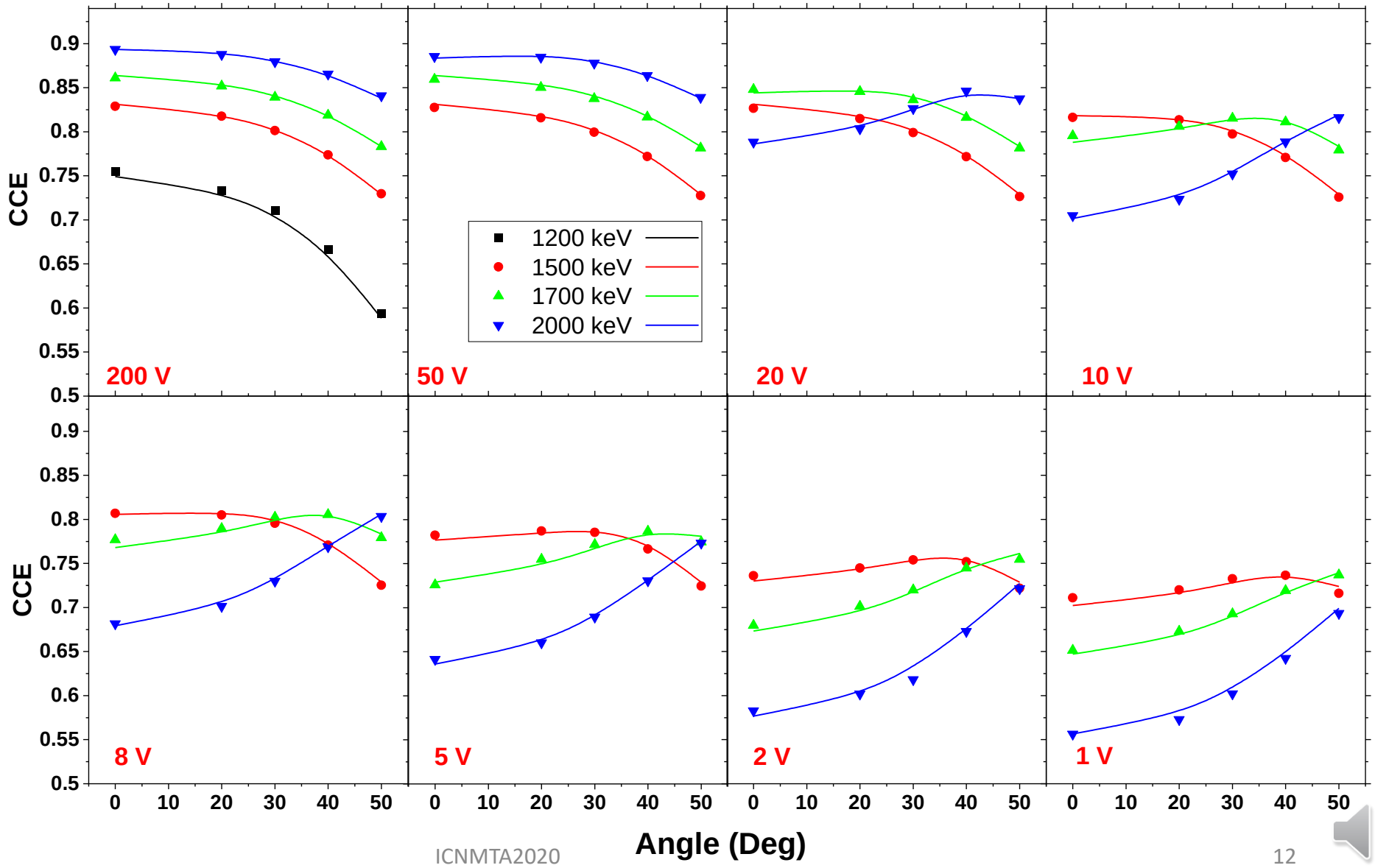
$$\begin{cases} \eta\left(x = w(V)\right) = 1 \\ \left.\frac{d\eta}{dx}\right|_{x=D} = 0 \end{cases}$$

Effect of the back surface field at the n-/n+ boundaries

Results: Model

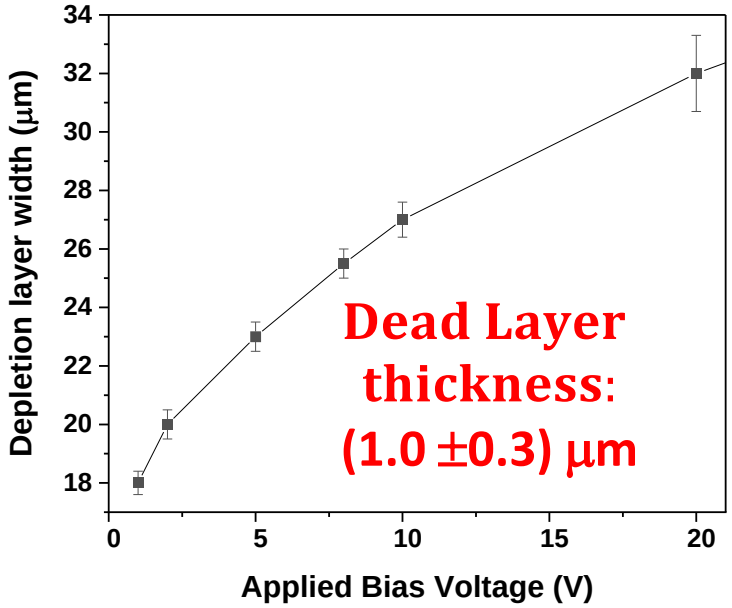
Solid lines are fitting curves

Experimental and fitting CCE as function of Tilting angle θ @ different V Parametrized by E

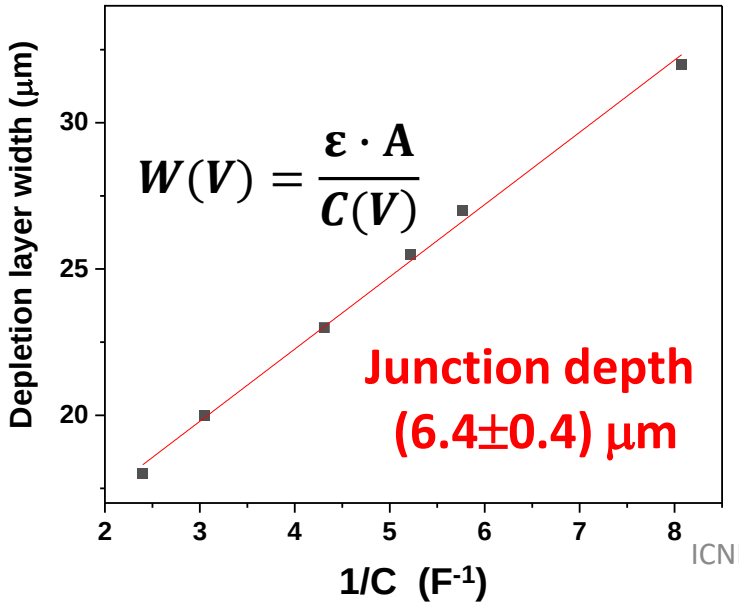


Results

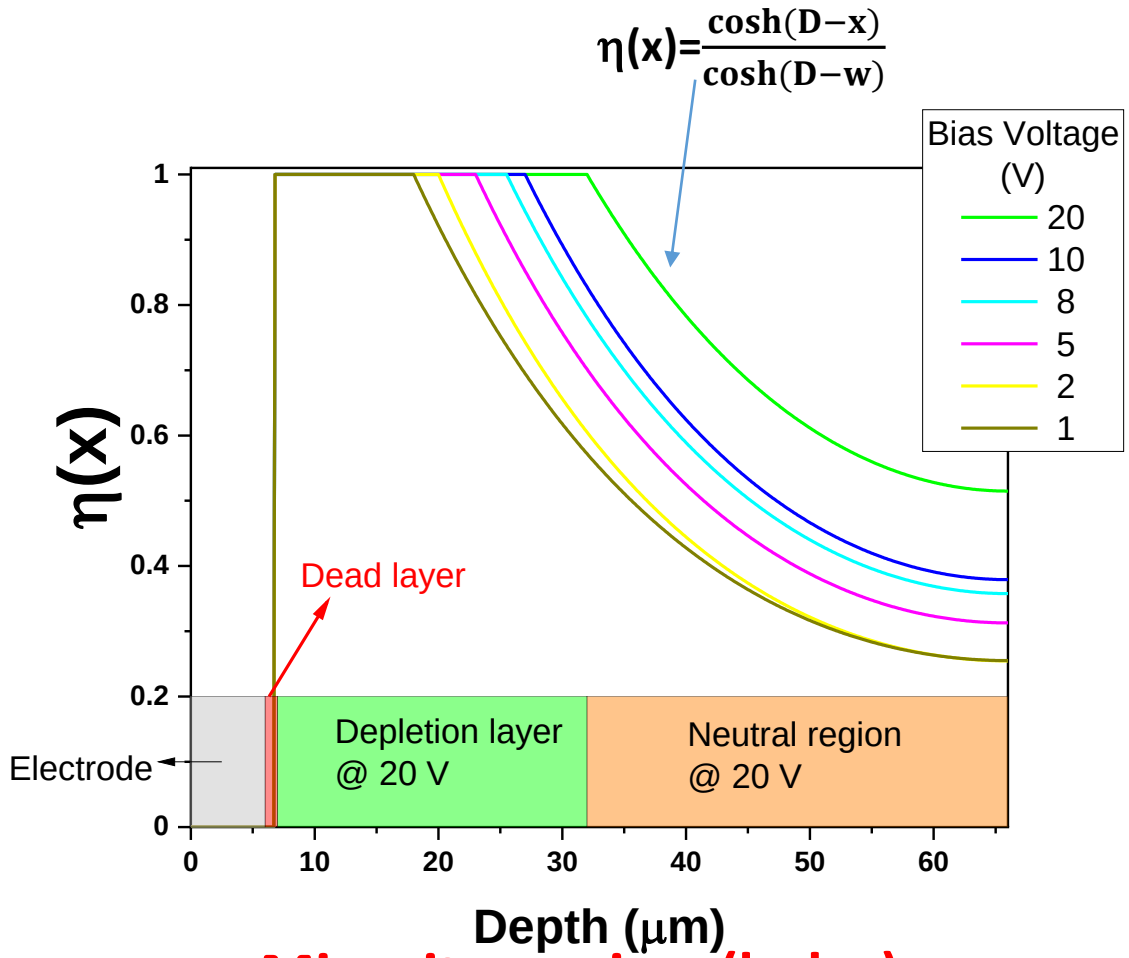
Behavior of the depletion layer width as function of the applied bias voltage



Linear relationship between inverse of capacitance and the depletion layer width



Charge collection efficiency profiles at different bias voltages



Minority carriers (holes) diffusion length:

L_h = (24.0±1.3) μm

Conclusions:

- **Polychromatic angle resolved Ion Beam Induce Charge technique was applied to characterize a p-i-n power diode**
- **Spectra extracted from the IBIC maps were measured as function of the**
  - **Proton energy (E=1200, 1500, 1700, 2000 keV)**
  - **Tilting angle (θ=0,20,30,40,50°)**
  - **Applied bias voltage (V=1,2,5,8,10,20,200 V)**
- **The analysis based on a simplified model of the IBIC theory was applied to extract the**
  - **Dead layer thickness (1.0 $\pm$0.3) μm**
  - **The diffusion length of minority carriers in the neutral region L_h = (24.0$\pm$1.3) μm**
  - **Behavior of the depletion layer width as function of the applied bias voltage in agreement with electrical characterization**
- **The fitting curves are in excellent agreement with the experimental data**

- **The methodology here developed is suitable for a non invasive functional analysis of power diodes and provides valuable parameters for the design of new semiconductor devices**