Infineon

Welcome

RD50, Liverpool :
Meeting from 23. – 25.05.2011

Some aspects of proton implantation and subsequent thermal annealing

Werner Schustereder

Infineon technologies

Never stop thinking.

Table of Contents

- Infineon at a Glance
- Business Focus
- Divisions, Products and Technology
- Some aspects of proton implantation and thermal annealing

Innovative semiconductor solutions
for energy efficiency, mobility
and security

Company Presentation
May 23, 2011

Infineon

Table of Contents

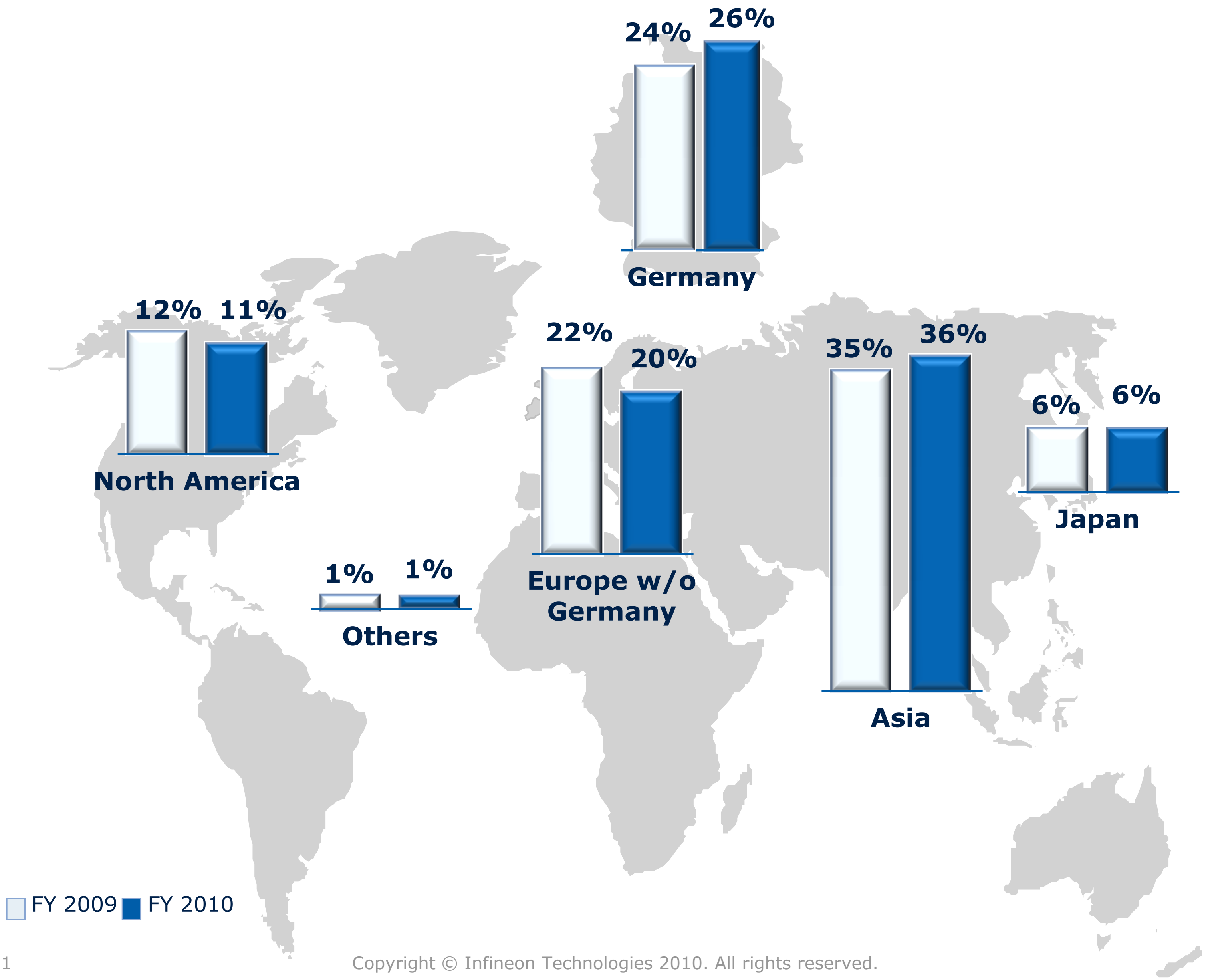
Infineon at a Glance

The Company

- Infineon provides semiconductor and system solutions, focusing on three central needs of our modern society: Energy Efficiency, Mobility and Security
- Revenue in FY 2010*: 3.295 billion EUR
- 25,119 employees worldwide (as of April 2011)
- Strong technology portfolio with about 15,400 patents and patent applications (as of Feb. 2011)
- More than 20 R&D locations
- Germany's largest semiconductor company

*Note: Figures according to IFRS with Wireline and Wireless as discontinued operations; as of September 30, 2010

Proportional Revenue Infineon Group by Regions
FY 2009 and FY 2010



Infineon – Worldwide Production Sites Frontend and Backend

🟩 Frontend 🟦 Backend

Infineon – Worldwide R&D Network (Excluding Europe)

Infineon – R&D Network in Europe

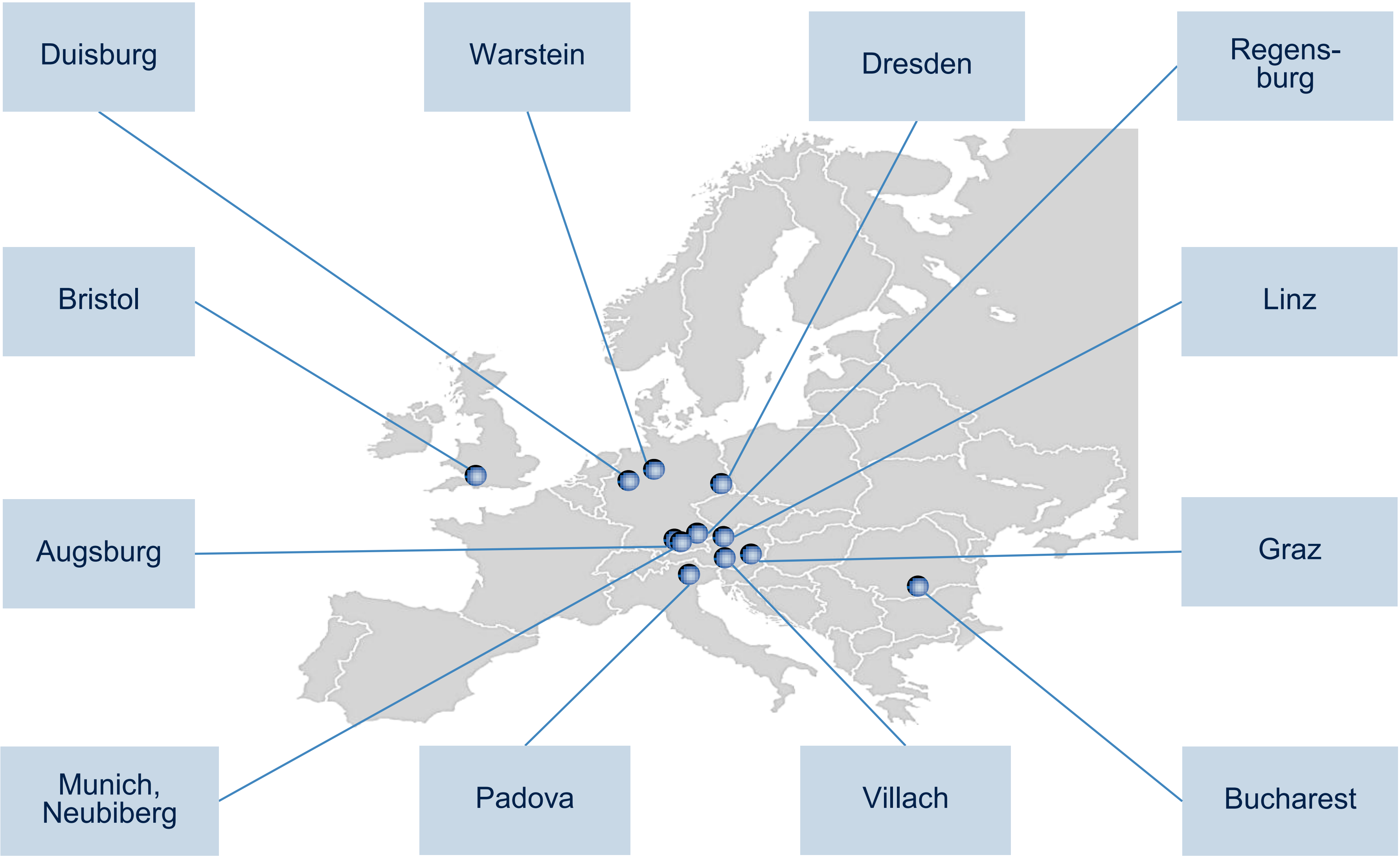


Table of Contents

We Focus on Our Target Markets

Focus Areas

- Energy Efficiency
- Mobility
- Security

Core Competencies

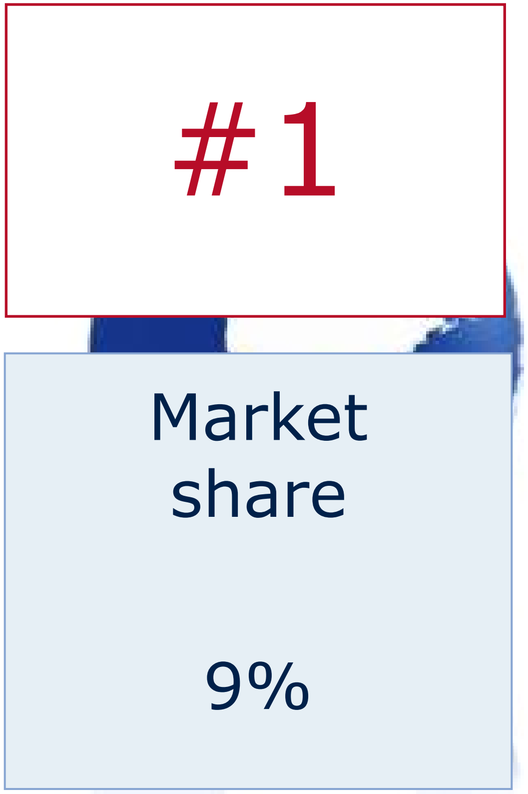
- Analog/Mixed Signal
- Power
- Embedded Control
- Manufacturing Competence

Our Target Markets

- Automotive
- Industrial Electronics
- Chip Card & Security

Infineon Holds a #1 Position in All Target Markets

Auto-motive



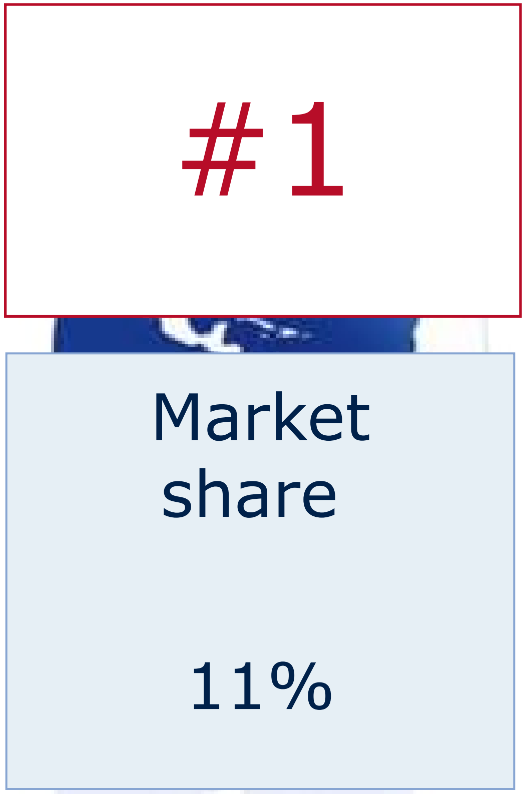
#1

Market share

9%

Calendar Year 2009
Source: Strategy Analytics, May 2010

Power



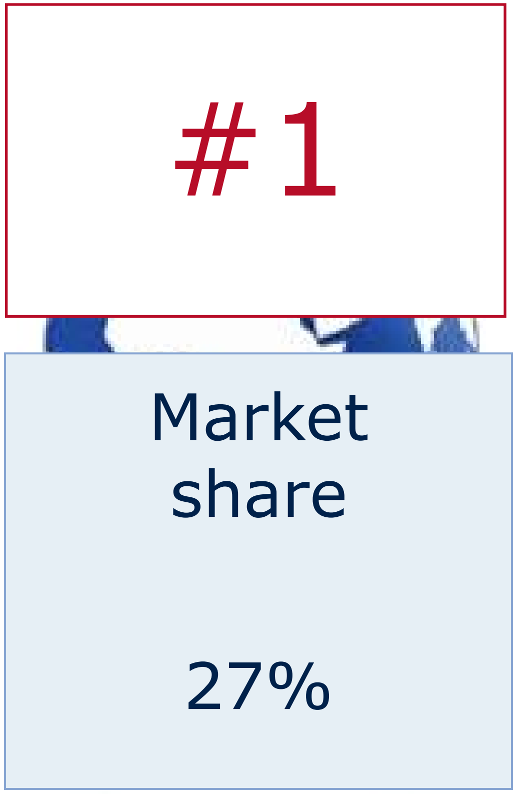
#1

Market share

11%

Calendar Year 2009
Source: IMS Research, July 2010

Chip Card



#1

Market share

27%

Calendar Year 2009
Source: Frost & Sullivan, October 2010

Table of Contents

We Focus on Future Business – Security Example 1: Protecting Privacy

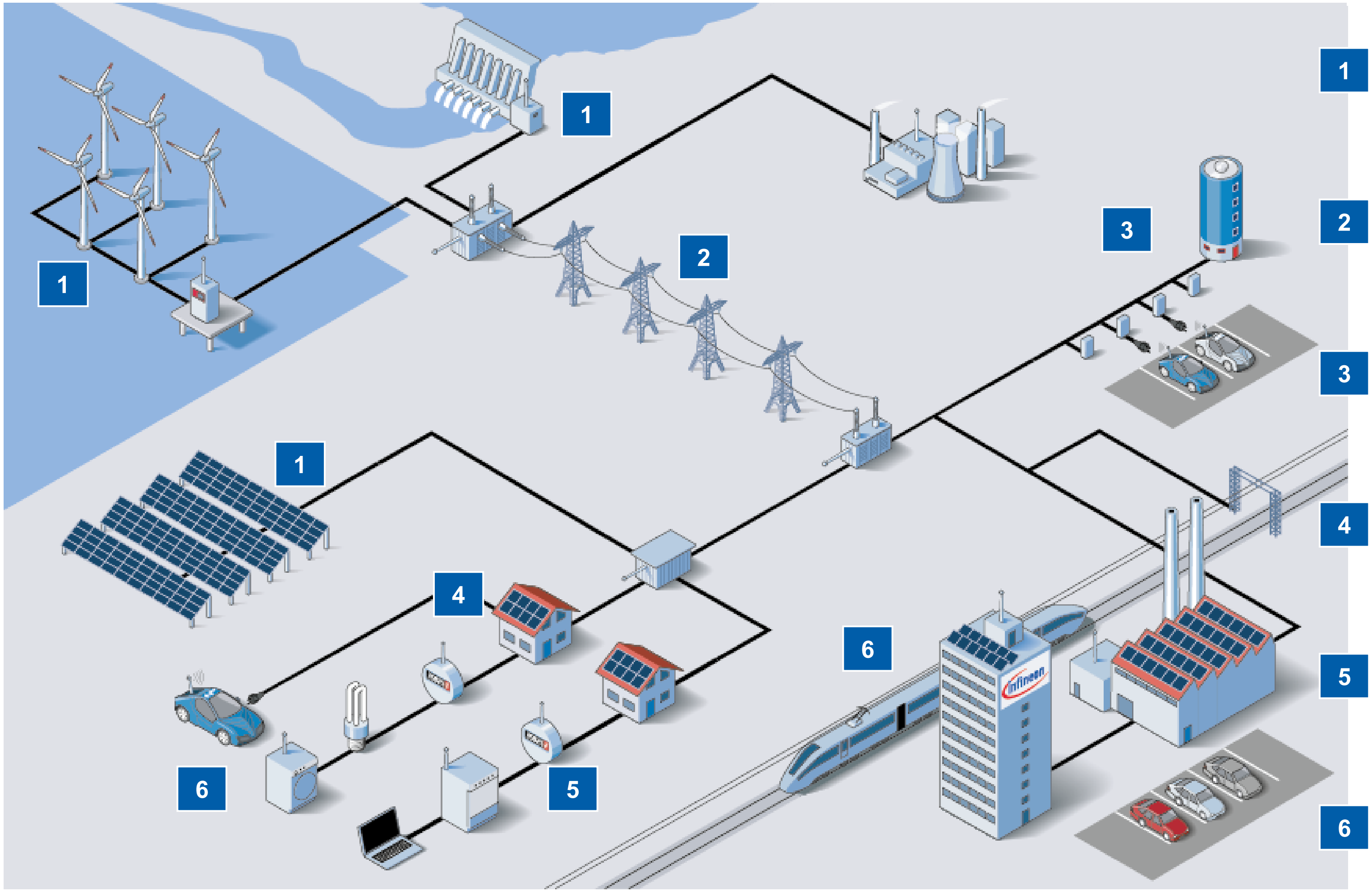
Market trends

- Trusted Platform Modules (TPM) on 70% of enterprise notebooks and desktops; Windows 7 support
- Data protection: Encryption of files, folders, disks, messaging, digital signatures
- Strong authentication: Network access protection and additional authentication factor

Infineon's opportunities

- No. 1 supplier for TPM solutions
- Infineon's TPM security chips are first to receive global TCG and Common Criteria Certification and UK government approval
- Chips for passports of USA & China

We Focus on Future Business – Energy Efficiency Example 2: Smart Grid



1	Renewable energies
2	Advanced transmission
3	EV charging and energy storage
4	Grid and smart meter security
5	Smart metering
6	Energy efficient consumption

We Focus on Future Business – Mobility Example 3: Making Cars Cleaner

Market trends

- Dwindling energy resources
- Stricter CO_2 emission legislations
- Growing environmental awareness

Infineon's opportunities

- Infineon components are key for CO_2 reduction: Total improvement of CO_2-emission ~23 g/km
- We offer Hybrid and electric drivetrain products (HybridPACK™)
- No electric vehicle without semiconductors: electric drive and control, battery management, on-board battery charging and power grid communication

Note: Baseline CO_2 reduction in g/km: 170 g/km on Ø EU cars

Table of Contents

Power Components for Drive Control of Train Systems

High-speed trains

Metro trains

Infineon parts

- Power: 5 to 10MW per train
- 80 to 120 IGBT modules per train
- Semiconductor content: ~EUR 100k per train

- Power: 0.5 to 1MW per train
- 25 to 50 IGBT modules per train
- Semiconductor content: ~EUR 10k per train

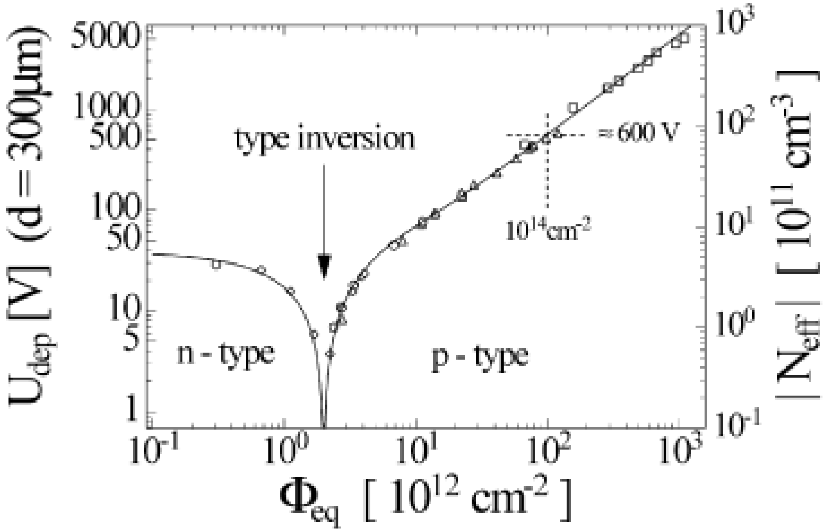
Concept of IGBT – rough overview

- Logic on front side of chip
- Source – Drain in 3D to allow switching of kV
- Suitable raw material and processing essential for excellent device characteristics
  - Low dark currents
  - High and stable break through voltage
  - Fast soft switching with minimal losses
  - …

- Several approaches to optimize processes in Si, one of them:
  - proton implantation in Si

Points of contact
(charged) particle interaction with Si

- CMS detectors: ~10^{14} – 10^{16} particles cm^{-2} / 10 years
  - Degradation of detectors – radiation hardness
  - → Investigate underlaying physical processes
    - Conversion from n-type to p-type Si
    - Which types of defects are formed, what can be done about it?
    - Investigate influence of raw material ((DO)FZ, (m)CZ, $[O_{(i)}]$, …)
    - …



Points of contact (charged) particle interaction with Si

- CMS detectors: ~10^{14} – 10^{16} particles cm^{-2} / 10 years
  - ☐ Degradation of detectors – radiation hardness

  → **Investigate underlaying physical processes…**
    - ¬ Conversion from n-type to p-type Si
    - ¬ Which types of defects are formed, what can be done about it?
    - ¬ Investigate influence of raw material ((DO)FZ, (m)CZ, $[O_{(i)}]$, …)
    - ¬ …
- Infineon: ~10^{12} – 10^{15} particles cm^{-2} @ every chip within ~50µm
  - ☐ Try to use initial defects of proton implantation
    - ¬ Fact: thermal treatment especially @ 350 – 500°C converts p-type → n-type material, but ***why & how***?

  → **Investigate underlaying physical processes…**

Methods

- Electrical properties of donator complexes

SRP	doping level as f(depth in Si)
C(U)	doping level, ev. as f(depth in Si)
Hall-Effect	mobility of charge carriers
EBIC	mobility of minority charge carriers

- Damaging behaviour as function of implant parameters

TWIN	crystall damage, ev. as f(depth in Si)

- Characterisation of damage centres

Positron analysis	Lifetime -> size of defects, ev. chemical surrounding
DLTS	trap parameters of defect centres
FIR spec.	energies of defects centres
PTIS	energies of defects centres
ESR	localize unpaired electrons

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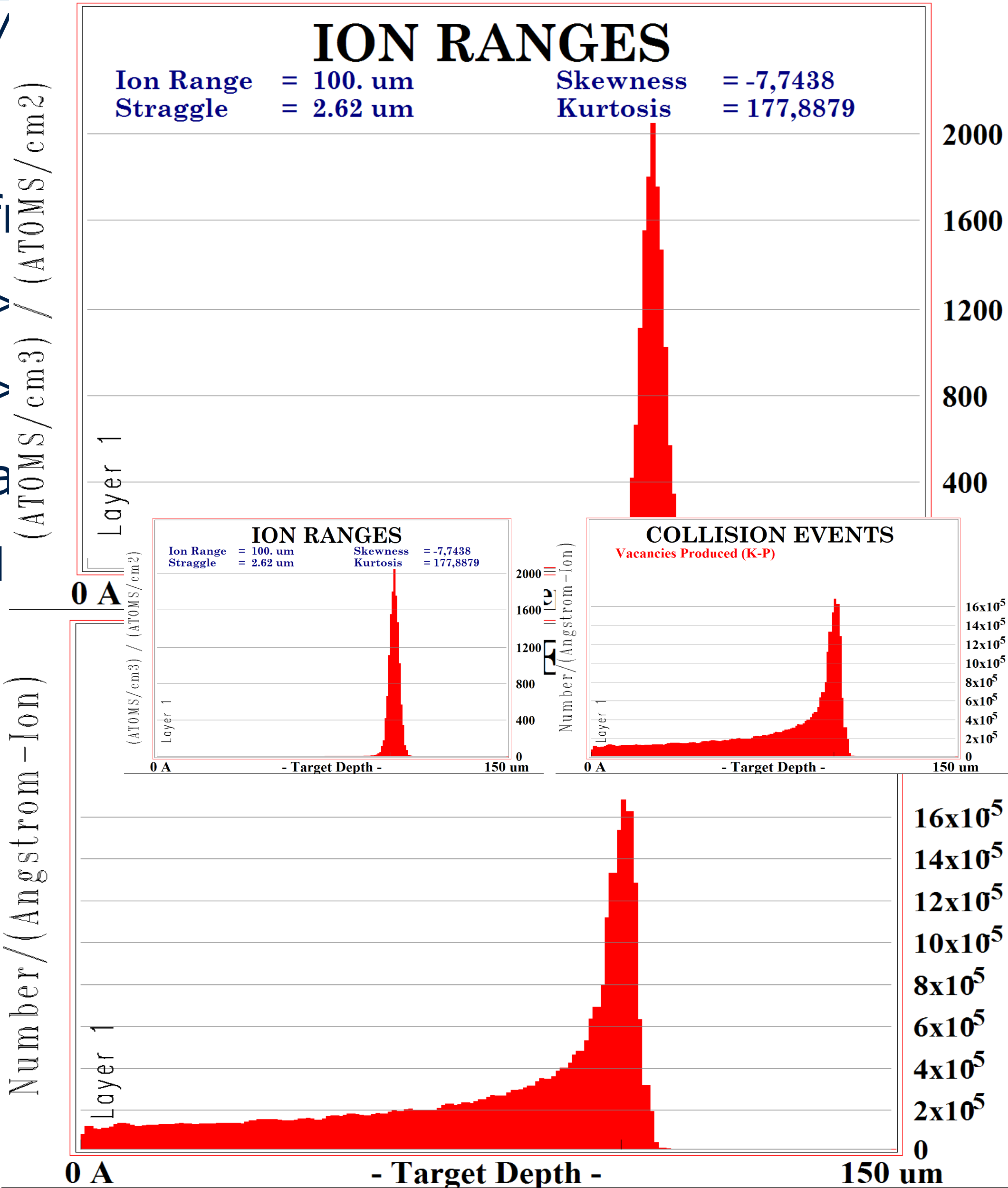
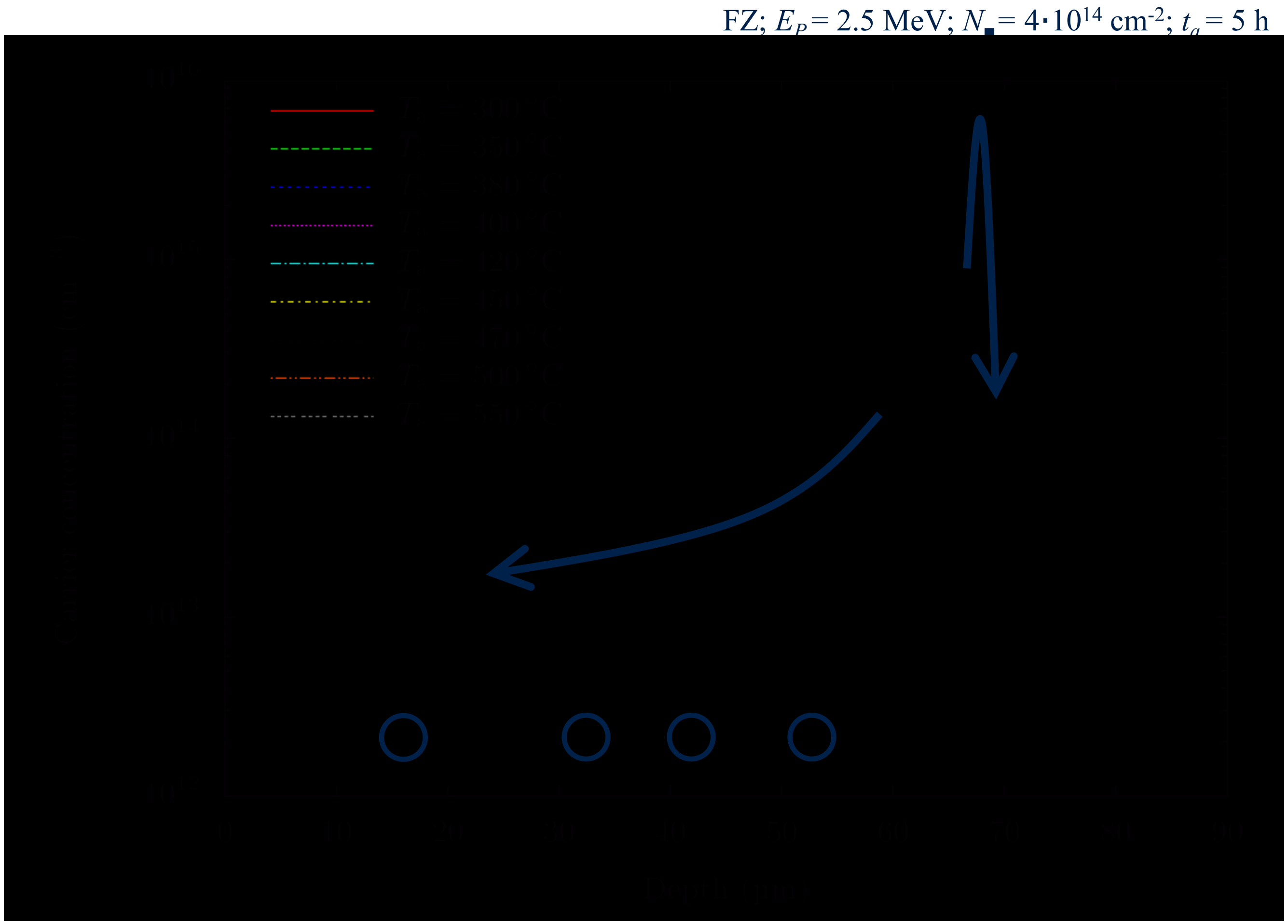
Process in short

- High energy proton [0.2; 4M
- Neutralisation of ion?
- Build-up of damage region f
  - Monovacancies V ->
  - Divacancies V_2 ->
- ☐ Passivation of raw materia
  - passivates B in p-type and
  - P in n-type Si



Annealing temperature (isochronal)

- Activation of H-rel. donors above T_a = 300 °C.
- Diffusion-like filling of the p-type penetrated range between T_a = 300 – 450 °C.
- Annealing of all generated shallow donors (SD) at T_a = 500 – 550 °C.



PhD Thesis Johannes Laven,
Fraunhofer Institut Erlangen

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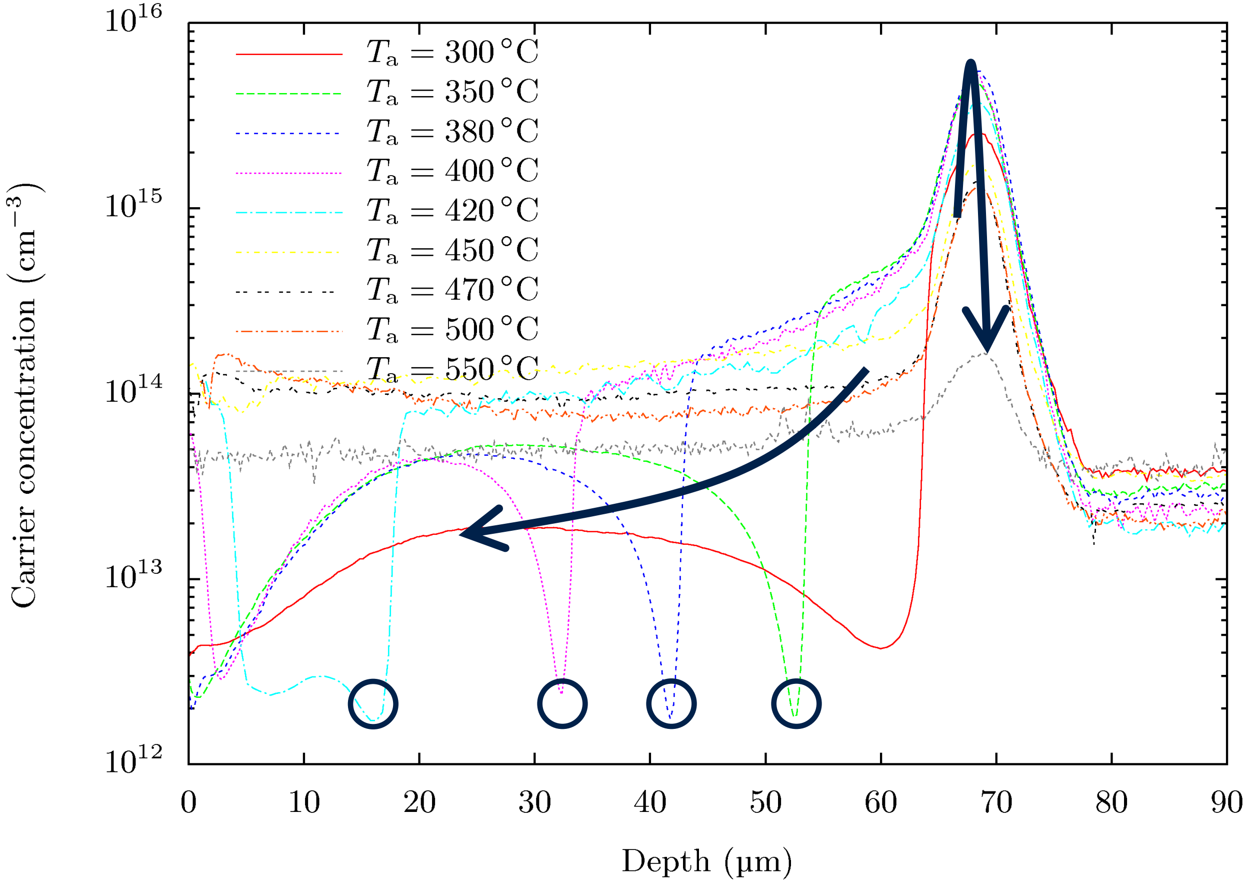

FZ; $E_P = 2.5$ MeV; $N_\blacksquare = 4\cdot10^{14}$ cm^{-2}; $t_a = 5$ h

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Fraunhofer Institut Erlangen

Profile-simulation concept

Split profile into:

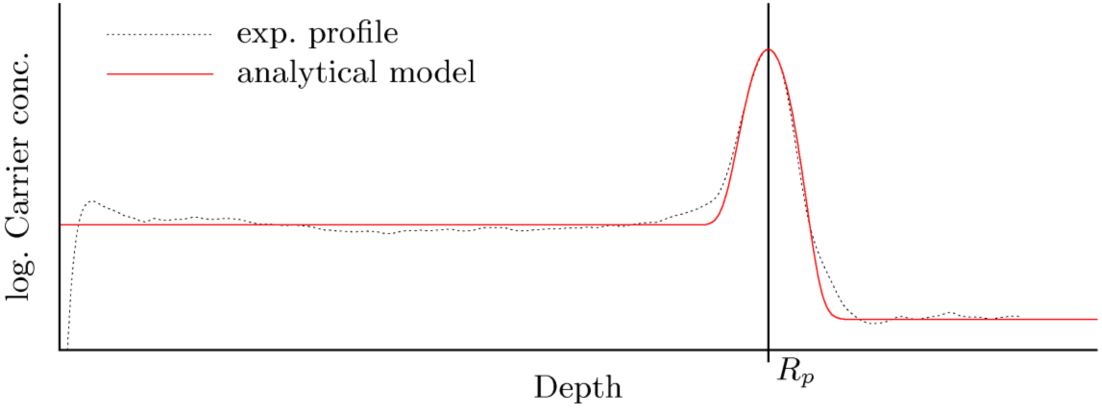
- Penetrated range $(T_a \geq 400°\mathrm{C})$
  - ☐ Linear function with carrier concentration $C_p(T_a)$.
  - ☐ $N_{\blacksquare}$-dependant ‘tilt’-correction necessary.
- Projected range $(T_a \geq 300°\mathrm{C})$
  - ☐ Gaussian at R_p with amplitude $C_R(T_a)$.
- Bulk region $(\forall\ T_a)$
  - ☐ Linear function with carrier concentration C_0.

$$C_S(x) = C_S(x, E_p, N_{\square}, T_a)$$

$$= C_0 + C_p \Theta(R_p - x) + C_R \cdot e^{-\frac{(R_p - x)^2}{2 \Delta R_p^2}}$$

where

$$C_R = a(E_p) \cdot b(T_a) \cdot N_{\square}^{\gamma}$$



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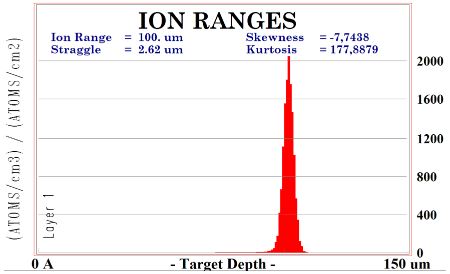
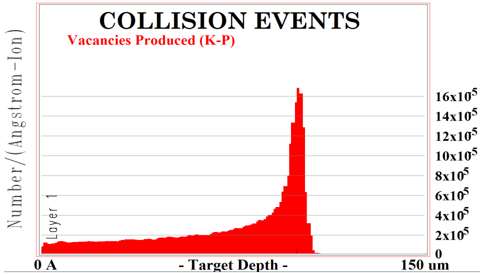
H diffusion in Si [Pearton]

- p-type Si: hydrogen present as H^+;
  - rapid diffusion (~10^{10}cm^{-2}s^{-1} @ RT)
  - T < 500°C: diff. impeded by trapping at acceptor ions
  - T > 500°C: diff. by rapid interstitial motion
- n-type Si: H^+ and H^0, depending on dopant density
  - D[H] considerably much lower compared to p-type Si
  - T < 150°C: donor-Si-H bonds can form impeding H motion & passivating donors
- Molecule formation can occur
  - H_2 much less mobile than atomic species and generally breaks up rather than diffuse
  - D[H_2] in n-type > D[H_2] in p-type

Process in short

- High energy proton [0.2; 4MeV] approaches Si Wafer
- Neutralisation of ion?
- Build-up of damage region from surface till end of range, f.e.
    - Monovacancies V -> anneal out immediately @ RT; → VO
    - Divacancies V_2 -> stable, may decorate with impurities
  - Passivation of raw material doping – amphoteric character of H
    - passivates B in p-type and also
    - P in n-type Si
  - Peak of H inside Si bulk





- Anneal ε [350, 500]°C → diffusion of H, enhanced D[O] ↔ D[H]
  - Growth of oxygen thermal donors (OTD)
  - Creation of different types as $f_{(Temp.)}$ of hydrogen donors
- Carrier concentration after anneal ~1% of implanted H dose

Mechanism for enhanced D[O]

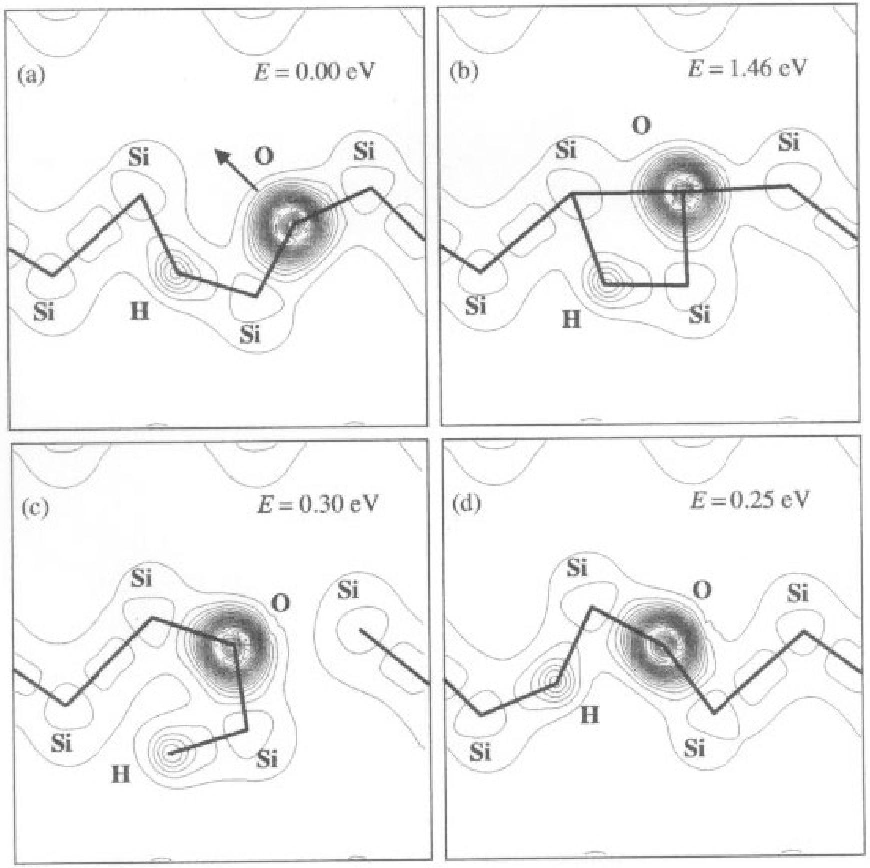
- H: highly mobile, f(T)
  - O diffusion rate can be enhanced by orders of magnitude due to lowering the saddle point energy in Si-O-Si transition from ~2.55 eV to ~1.46 eV with nearby atomic H
  - Calculations; f.e. MD by *Capaz et al*

    a) Initial ground state configuration with BC O and H

    b) Saddle-point configuration with max. E_{pot} = 1.46 eV above the gr.st.

    c) Metastable state with 0.30 eV with H-saturated Si-Si broken bond

    d) Final ground-state configuration with BC O and H



Oxygen diffusion in turn interacts with hydrogen and decreases D[H]

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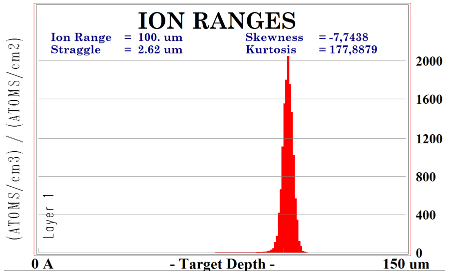

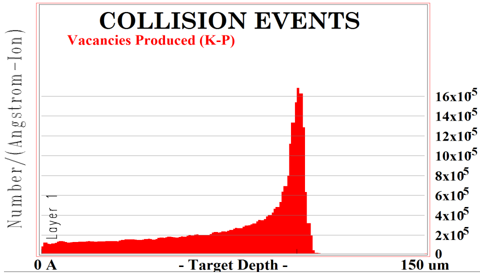

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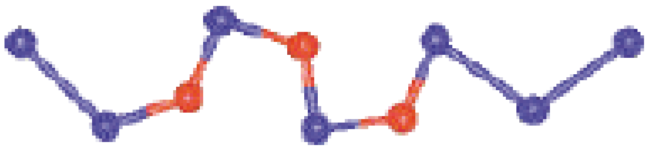
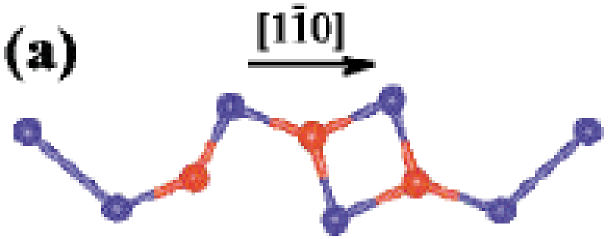
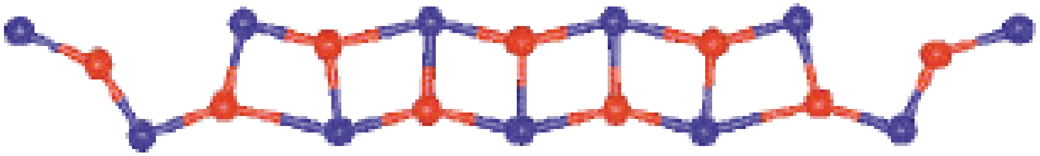
Configurations of O_i in Si
Oxygen thermal donors (OTD)

- Formation of OTD: Si ● O ●
  - ☐ electrical inactive: electrical active ring structure:

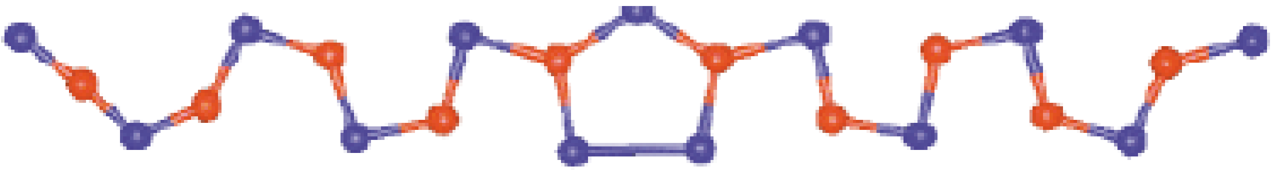




  - ☐ Growth of ring structure, up to ~ 8 O atoms involved:



  - ☐ Rings with more than 8 O atoms are electrically inactive
  - ☐ Concurring structure: “di-Y-lid“, also el. inactive



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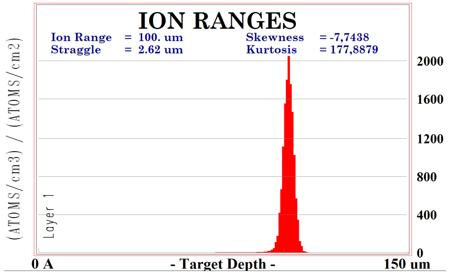

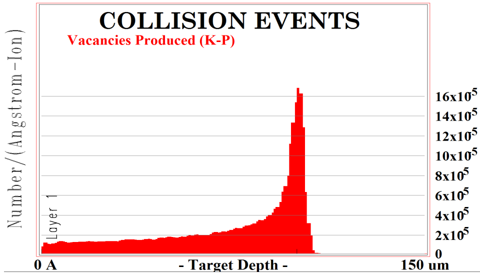

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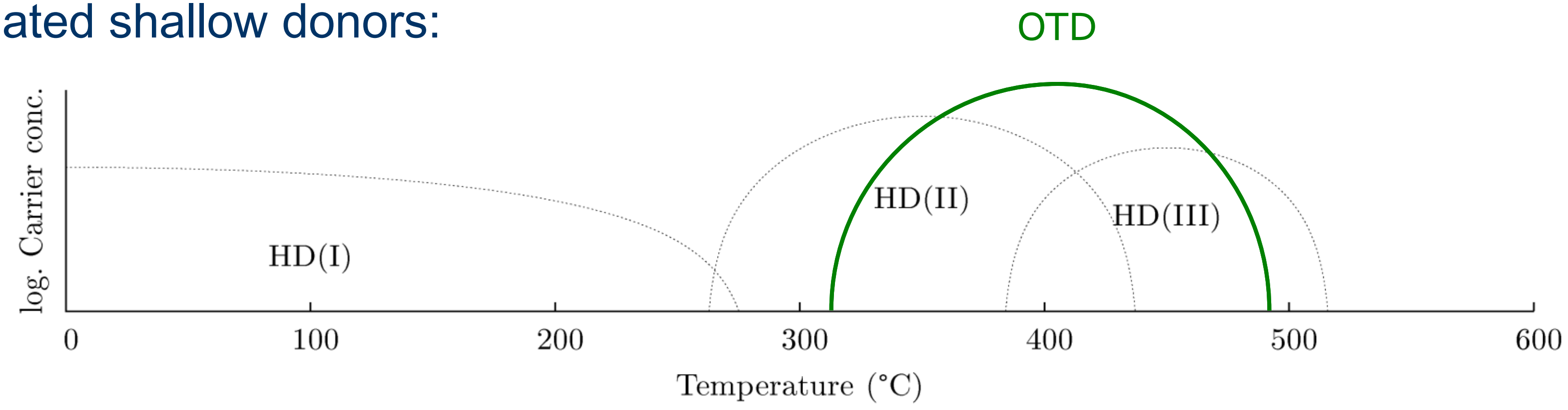
Different types Hydrogen Donors (HD)

H-related shallow donors:



HD(I)

- [C_iO_i-H]-Complex?

HD(II)

- IR absorption spectra are similar to TDDs
- Spectra differ under stress
- I-rel. extended defects?

\- $E^{0/+}$: E_C - 66 meV *

\- $E^{++/+}$: E_C - 100 meV *

HD(III)

- IR absorption spectra show Si-H vibrations with identical annealing behavior
- Multiple levels

\- E_C - (35 – 44) meV **

\- E_C - (26 – 53) meV

Also literature reports on 3 different types of donors; e.g. Tokuda et al., Hatakeyama et al.

*: Mukashev et al, 1985 Abdullin et al, 2004

**: Hartung and Weber, 1993 Markevichetal, 1998

Creation of Hydrogen Donors (HD)

- Fact: concentration of donors ~1% of implanted H
  - Open questions
    - Correlation (Transition?) of STD with OTD unclear
    - Correlation of STD with O concentration [also Lit: f.e. Navarro]
    - Possible complex influence of N concentration [Hartung]
    - Role of C unclear

Influence of raw material: FZ vs. mCZ

- Surface:

  $N_{\square}$-dependency more pronounced in mCZ

- Penetrated range:

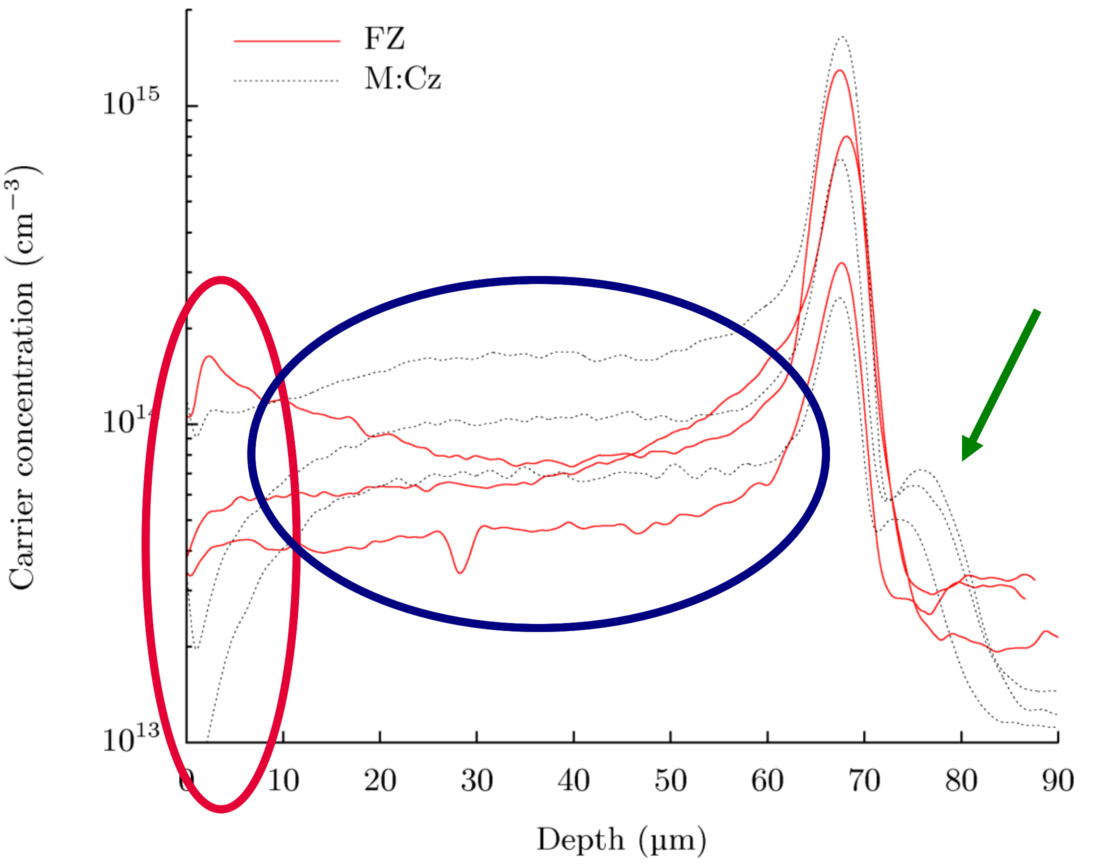
  FZ: stays longer @ *p*-type for lower Temps / shorter annealing times

  mCZ: shows higher resistance values for lower Temps / shorter annealing times

- Shoulder:

  in FZ only visible for very high $N_{\square}$

$E_P = 2.5$ MeV; $T_a = 470$ °C; $t_a = 5$ h



Furthermore: Carrier concentration non-linear with proton dose > ~4E14

Summary

- Some CC profiles of proton implanted Silicon have been shown
- Dependencies examined are mainly
  - $E_p = 0.5 - 4.0$ MeV $N_{\square} \sim 10^{13} - 10^{15}$ cm^{-2}
  - $T_a = 300 - 550$ °C $t_a = 0.5 - 30$ h

Outlook

- **Common interest: Investigate & understand underlaying physical processes of particle (proton) irradiation in Si**
  - ☐ Intrinsic fundamental interest
  - ☐ Avoid detector degradation (CERN)
  - ☐ Use defect properties to tailor semiconductor properties (Infineon)

Methods

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- Techniques for characterisation

ENERGY EFFICIENCY
MOBILITY
SECURITY

Innovative semiconductor solutions for energy efficiency, mobility and security.