Last (43rd) RD50 Workshop on Radiation Hard Semiconductor Devices for Very High Luminosity Colliders (CERN)

28 novembre 2023 a 1 dicembre 2023
CERN
Europe/Zurich fuso orario

Inserisci il termine di ricerca

How RD50 started

Mara Bruzzi

University of Florence and INFN Firenze

UNIVERSITÀ DEGLI STUDI FIRENZE

INFN Istituto Nazionale di Fisica Nucleare

The CERN RD50 Collaboration

http://www.cern.ch/rd50

RD50: Development of Radiation Hard Semiconductor Devices for High Luminosity Colliders

- Approved as RD50 by CERN in June 2002
- Main objective:

Development of ultra-radiation hard semiconductor detectors for the luminosity upgrade of the LHC to 10^{35} $cm^{-2}s^{-1}$ ("Super-LHC").

Challenges:
- Radiation hardness up to 10^{16} cm^{-2} required
- Fast signal collection (Going from 25ns to 10 ns bunch crossing ?)
- Low mass (reducing multiple scattering close to interaction point)
- Cost effectiveness (big surfaces have to be covered with detectors!)

252 Members from 50 Institutes

Belarus (Minsk), Belgium (Louvain), Canada (Montreal), Czech Republic (Prague (2x)), Finland (Helsinki, Lappeenranta), Germany (Berlin, Dortmund, Erfurt, Hamburg, Karlsruhe), Israel (Tel Aviv), Italy (Bari, Bologna, Florence, Padova, Perugia, Pisa, Trento, Trieste, Turin), Lithuania (Vilnius), Norway (Oslo (2x)), Poland (Warsaw), Romania (Bucharest (2x)), Russia (Moscow), St.Petersburg), Slovenia (Ljubljana), Spain (Barcelona, Valencia), Switzerland (CERN, PSI), Ukraine (Kiev), United Kingdom (Exeter, Glasgow, Lancaster, Liverpool, Sheffield, University of Surrey), USA (Fermilab, Purdue University, Rochester University, Rutgers University, SCIPP Santa Cruz, Syracuse University, BNL, University of New Mexico)

The CERN RD50 in 2004

52 Institutes - 254 participants

Barcelona CNM, Bari INFN & University , Berlin IKZ, Brookhaven National Laboratory, Bologna University, Bucharest NIMP, Bucharest University, CERN, Dortmund, CiS Erfurt, Exeter University, Fermilab, Florence INFN and University, Glasgow University, Hamburg University, Helsinki HIP, Ioffe St. Petersburg, ITE Warszawa, ITME Warszawa, Karlsruhe University KINR Ukraine, Lancaster University, Lappeenranta University of Technology Finland, Liverpool University, University of Ljubljana, Institut de Physique Nucléaire Louvain, Minsk Belarusian University, Montreal University, Moscow ITEP, University of New Mexico, University of Oslo, Padova INFN & University, Perugia INFN and University, Pisa INFN and University, Prague Academy Institute of Physics, Charles University Prague, Prague CTU, Paul Scherrer Institut Villigen, Purdue University, University of Rochester, Rutgers University, Santa Cruz Institute for Particle Physics, University of Sheffield, SINTEF Oslo, University of Surrey, Syracuse University, Tel Aviv University, University of Torino, Trento ITC-IRST Microsystems Division, Trieste INFN and University, Valencia IFIC, Vilnius University

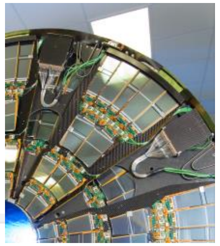
Brief history of CERN RDs

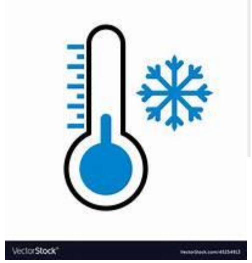
CERN-RD-002 (CERN)

Study of a Tracking/Preshower Detector for the LHC
(Approved: Sep 20, 1990, Completed: Nov 24, 2004)
RD2 Collaboration

1990-2004

large-area silicon tracking detectors may be used at LHC





CERN-RD-039 (CERN)

Cryogenic Tracking Detectors
RD39 Collaboration

1999-2013

Optimization of silicon tracking detectors working at low T ≈ 130K

T.Niinikoski, J. Harkonen

1994 -

A DIAMOND IS FOREVER

CERN-RD-042 (CERN)

H. Kagan, (P. Weilhammer) W. Trischuk

Development of Diamond Tracking Detectors for High Luminosity Experiments at the LHC
RD42 Collaboration

CERN-RD-050 (CERN)

2002 - 2023

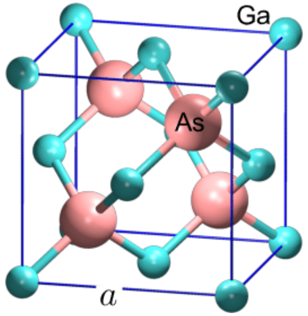
Development of Radiation Hard Semiconductor Devices for Very High Luminosity Colliders
RD50 Collaboration

CERN-RD-008 (CERN)

1992-1998

Development of GaAs Detectors for Physics at the LHC
RD8 Collaboration

First WBG under study at CERN



CERN-RD-019 (CERN)

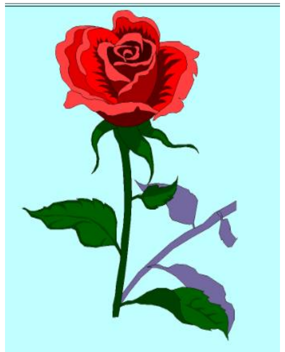
2001 - 2010

Development of hybrid and monolithic silicon micropattern detectors
(Approved: Jun 27, 1991, Completed: Jun 10, 2010)
RD19 Collaboration

E.Heijne

CERN-RD-048 (CERN)

Radiation Hardening of Silicon Detectors
Rose Collaboration



1995 - 2000

F.Lemeilleur,
G.Lindstroem,
S.Watts

ROSE: R&D On Silicon for future Experiments

M. Bruzzi 2002-2009,
M. Moll 2005 -
G. Casse 2012 -

Main motivations for R&D on Radiation Tolerant Detectors: Super - LHC

- **LHC upgrade**

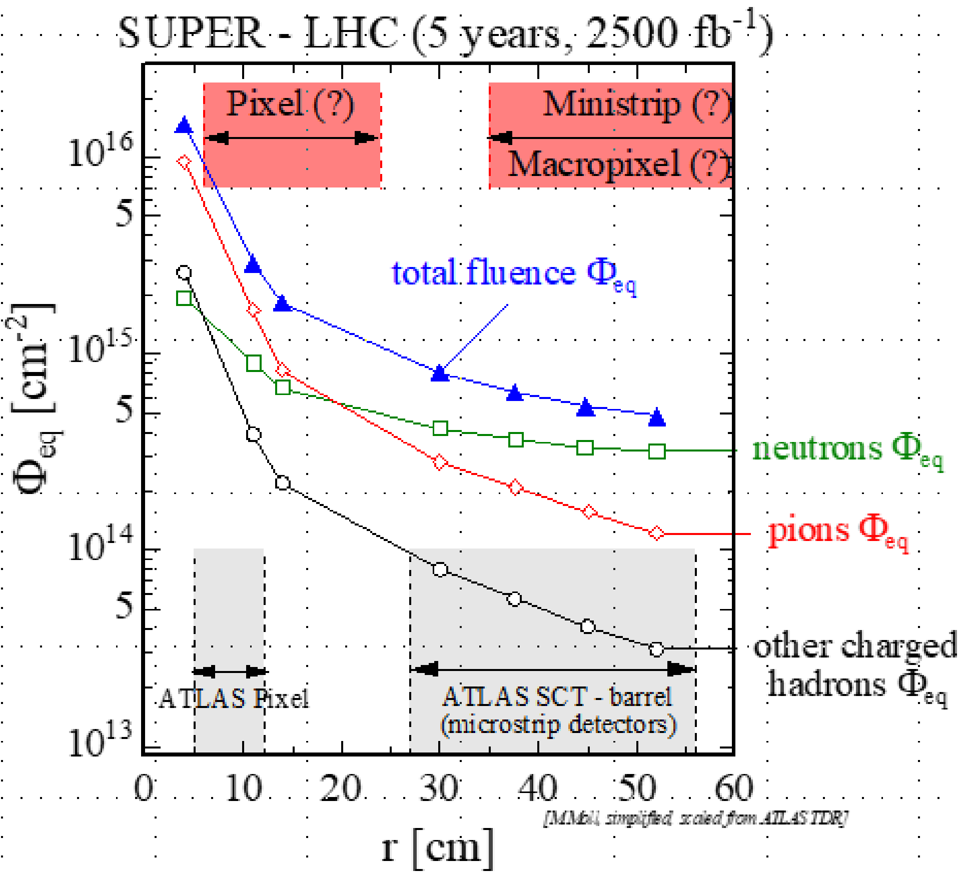
  ⇨ **LHC (2007), $L = 10^{34} cm^{-2}s^{-1}$**

  10 years / 500 fb^{-1} → $\phi(r=4cm) \sim 3 \cdot 10^{15} cm^{-2}$

  × 5

  ⇨ **Super-LHC (2015 ?), $L = 10^{35} cm^{-2}s^{-1}$**

  5 years / 2500 fb^{-1} → $\phi(r=4cm) \sim 1.6 \cdot 10^{16} cm^{-2}$



- **LHC (Replacement of components)**

  e.g. - LHCb Velo detectors (~2010)

  - ATLAS Pixel B-layer (~2012)

- Linear collider experiments (generic R&D)

  Deep understanding of radiation damage will be fruitful for linear collider experiments where high doses of e, γ will play a significant role.

THE ROSE COLLABORATION

The ROSE Collaboration

CERN - RD48

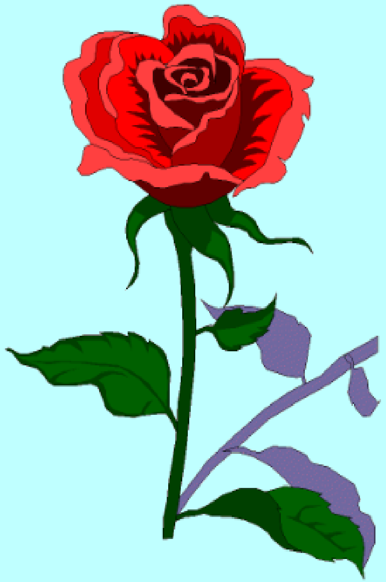
ROSE

Research and development
On Silicon for future Experiments

RD48 Spokespersons:
Dr. Francois Lemeilleur
Prof. Dr. Dr. hc. Gunnar Lindström
Prof.Dr. Stephen J. Watts

ROSE representative at CERN:
Dr. Michael Moll

About ROSE



The work of the ROSE collaboration was concluded end of 2000. Starting form the year 2001 the RD50 collaboration is working on the development of radiation tolerant semiconductor detectors.

ROSE: R&D On Silicon for future Experiments

- **Founded in 1995, formally approved by LHCC in 1996, ended successfully in December 2000**
  39 collaborating institutes, 7 associated companies, 3 observers
- **Final report CERN/LHCC 2000-09**

PROPOSAL FOR FURTHER WORK ON RADIATION HARDENING OF SILICON DETECTORS

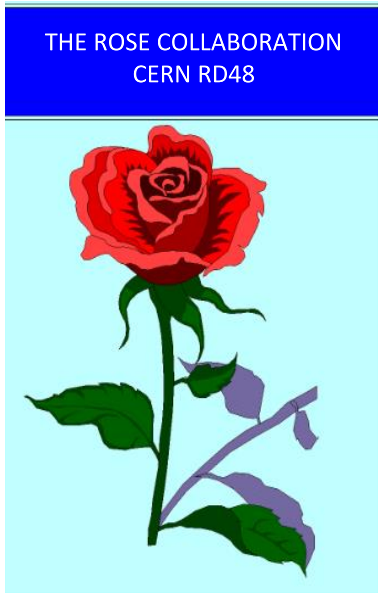
CERN/LHCC 96-23
P62 / LHC R&D

The ROSE Collaboration (R & d On Silicon for future Experiments)

Co-Spokespersons: Francois Lemeilleur, Gunnar Lindstroem, Steve Watts

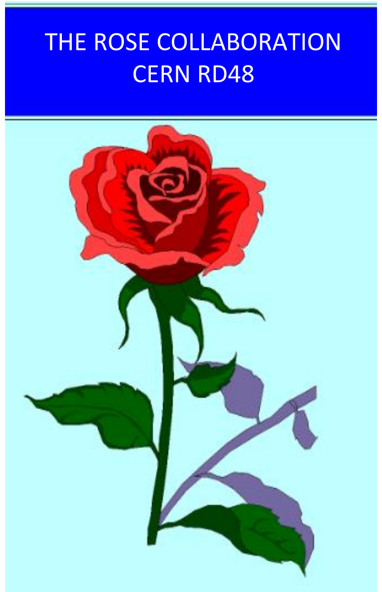
23 April 1996

- Brookhaven National Laboratory, USA H. W. Kraner, Z. Li
- Brunel University, UK A. Holmes-Siedle, I. Hopkins, J. Matheson, M. Solanky, S. Watts
- Institute of Nuclear Physics and Engineering, Bucharest, Romania A. Vasilescu
- Institute of Physics and Technology of Materials, Bucharest, Romania T. Botila, D. Petre, I. Pintilie, L. Pintilie
- University of California, Dept. of Materials Science, Berkeley , USA E. Weber
- University of Catania, Italy S. Albergo, R. Potenza
- Dortmund University, Germany C. Becker, A. Rolf, R. Wunstorf
- CERN, ECP Division, Switzerland G.L. Casse, B. Dezillie, M. Glaser, F. Lemeilleur, C. Leroy
- CERN, PPE Division, Switzerland S. Roe, P. Weilhammer
- Universita di Firenze, Italy U. Biggeri, E.Borchi, M.Bruzzi, E.Catacchini, E. Focardi, G. Parrini
- Hamburg University, Germany H. Feick, E. Fretwurst, G. Lindstroem, M. Moll
- Imperial College, University of London, UK. B. MacEvoy, G. Hall
- INFN, Pisa, Italy. R. Dell'Orso, A. Messineo, G. Tonelli, P. Verdini, R. Wheadon
- Kings College, University of London, UK G. Davies
- Institute for Nuclear Research, Kiev, Academy of Sciences, Ukraine P. Litovchenko
- Max Planck Institute, Munich, Germany G. Lutz, R.H. Richter
- Universita di Padova, Italy N. Bacchetta , D. Bisello, A. Giraldo
- Czech Technical University of Prague, Czech Republic S. Pospisil, B. Sopko
- PSI, Switzerland K. Gabathuler, R. Horisberger
- Laboratory of Non-Equilibrium Processes in Semiconductors, Ioffe Physico-Technical Institute, St. Petersburg, Russia V. Eremin, E. Verbitskaya
- University of New Mexico, USA J.A.J. Matthews, S. Seidel
- University of Perugia, Italy P. Bartalini, G.M. Bilei, P. Ciampolini, D. Passeri, A. Santocchia
- Institute of Nuclear Physics Demokritos , Greece G. Fanourakis, D. Loukas, A. Markou, I. Siotis, S. Tzamarias, A. Vayaki



ROSE – oxygenated silicon

Francois Lemeilleur, Gunnar Lindström, Steve Watts
for the
CERN RD48 (ROSE) collaboration



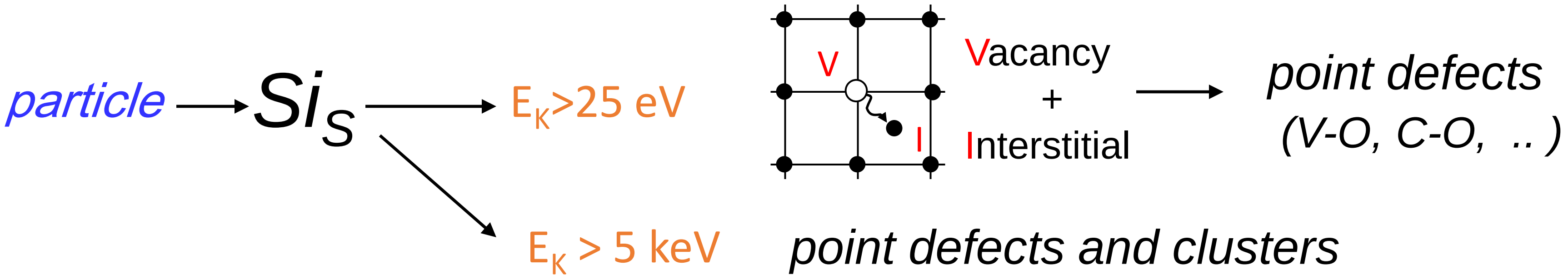
ROSE: R&D On Silicon for future Experiments

- **Goals:**
  - Development of radiation hard Si-detectors operable beyond the limits of 1996-state of the art devices, ensuring operation for whole lifetime of LHC experimental program
  - Recommendations to experiments on optimum Si and quality control to ensure radiation tolerance

- **Main focus:**
  - Defect engineering by DOFZ Oxygen enrichment: Diffusion of oxygen during manufacturing process ensures cost effectiveness
  - Radiation hardness issues: Tolerable depletion voltage, good charge collection; Leakage current by cooling
  - Dependence on material and particle type, NIEL scaling?
  - Understanding on microscopic scale, using DLTS and similar methods for detection of defects, studying kinetics and correlations with macroscopic behaviour

Universität Hamburg

Radiation Damage – A microscopic view



Defect and material characterization

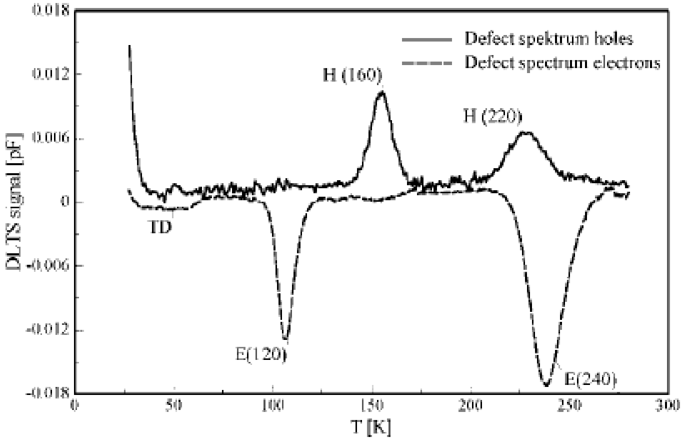
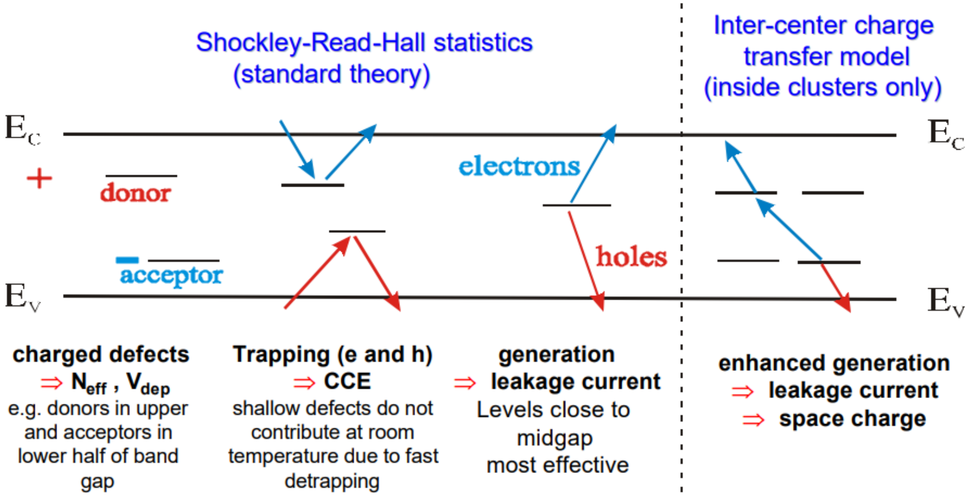


Figure 1.: DLTS-measurement of electron and hole traps in a 24h oxygenated <100> sample.

Name	sign	E_a[eV]	$\sigma_{n,p}$[cm^2]
TDD	E	-0.137	$1.58 \cdot 10^{-13}$
E(120)	E	-0.236	$1.00 \cdot 10^{-14}$
E(240)	E	-0.545	$5.41 \cdot 10^{-15}$
H(160)	H	+0.370	$2.88 \cdot 10^{-13}$
H(220)	H	+0.494	$1.65 \cdot 10^{-14}$

Table 3.: Electrical properties of the material defects

Impact of Defects on Detector properties



Impact on detector properties can be calculated if all defect parameters are known:

$\sigma_{n,p}$: cross sections **ΔE : ionization energy** **N_t : concentration**

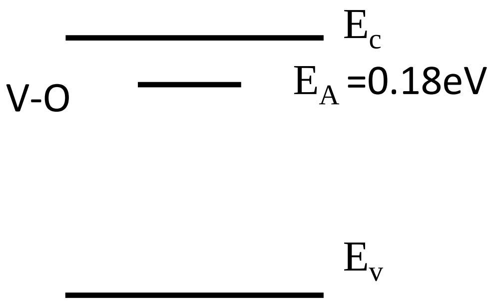
Si - Vacancy related point-defects: The A centre

oxygen-doped silicon dominant centers of vacancy capture may be isolated interstitials O_i and trapping results in the formation of the V-O centre, so-called A centre

Oxygen: as interstitial, up to $10^{18}cm^{-3}$ in Cz Si, (in Float Zone $[O_i]$~$10^{15}cm^{-3}$), electrically inert.

It may give rise to **shallow thermal donors (TDs)** small clusters of atoms formed at the early stages of oxygen aggregation, if $[O_i]$~ $10^{17}cm^{-3}$ or higher.

V-O defect (A centre)



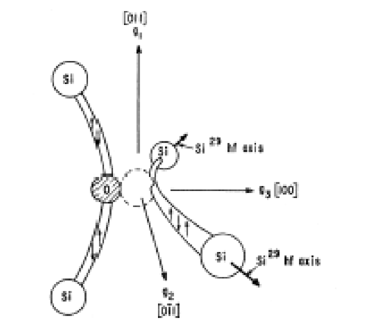


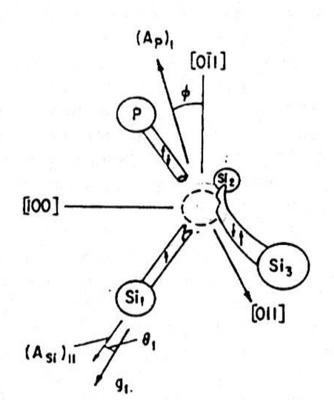
FIG. 5. Model of the A center as a substitutional oxygen atom. The oxygen atom bonds between two of the four neighboring silicon atoms, and the remaining two silicon atoms pull together to form a covalent bond. Spin resonance arises from an additional electron which is trapped in the Si—Si molecular bond as shown. The g tensor and hyperfine axes are indicated.

Watkins, Corbett: Phys.Rev.,121,4, (1961),1001

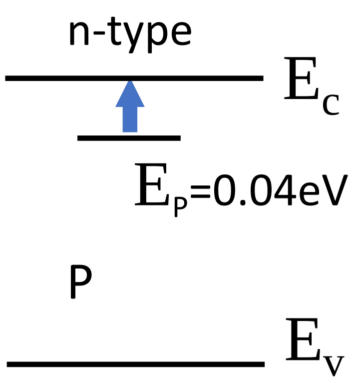
Doped Si - Vacancy related point-defects: The E centre

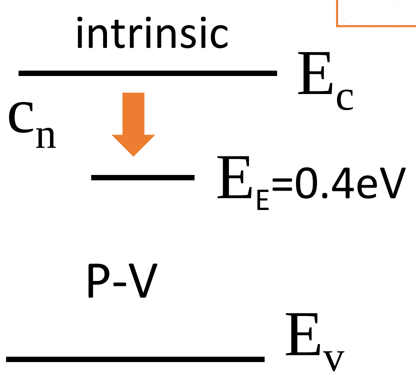
shallow dopants trap vacancies creating deep defects

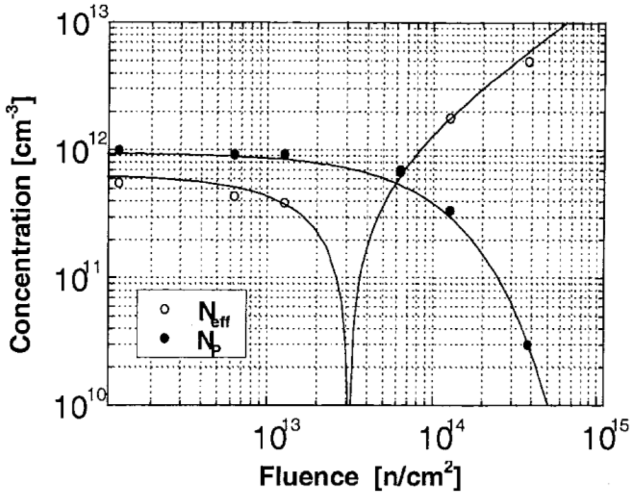
P-V (E centre)



→ carrier removal
→ intrinsic after heavy irradiation





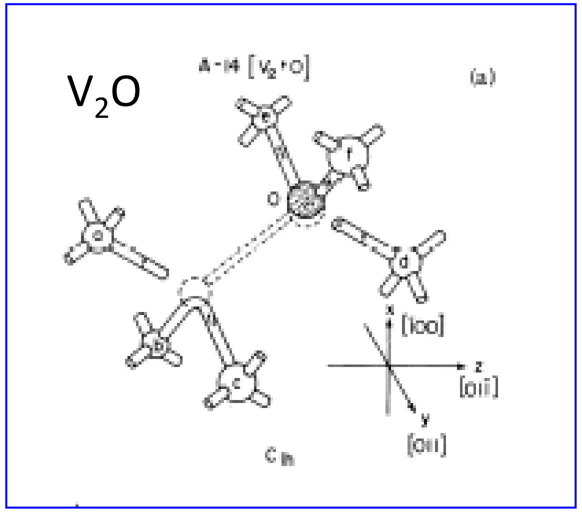


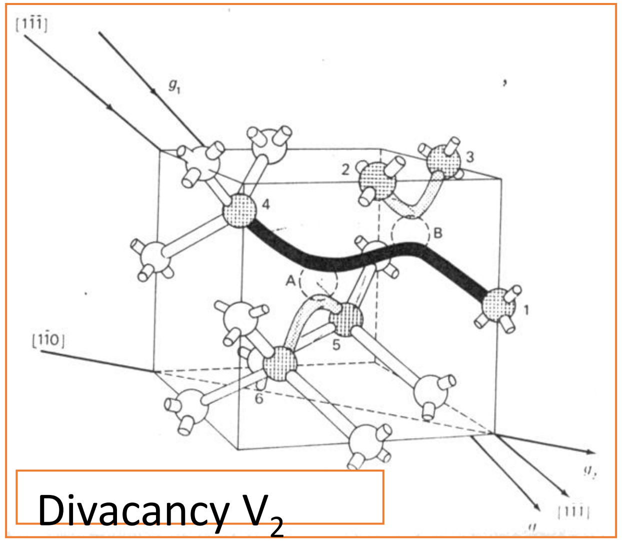
Borchi, Bruzzi, Li Pirollo, IEEETNS 47, 2000

Point-defects involving more than one vacancy

Lee, Corbett: Phys.Rev.B,13,6, (1976),2653

V_2, V_2O, V_3O etc..

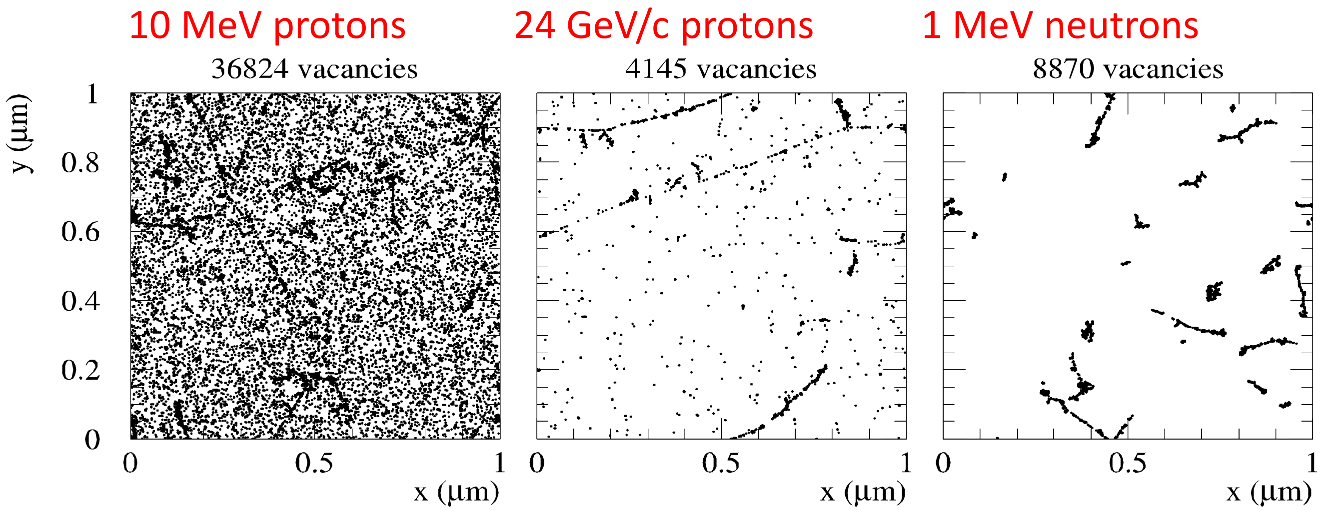




.. And CLUSTERS

[Mika Huhtinen NIMA 491(2002) 194]

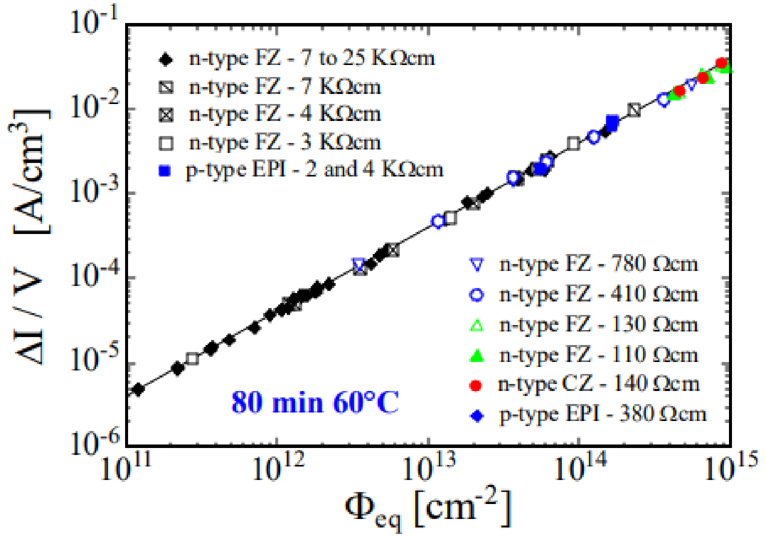
Initial distribution of vacancies in $(1\mu m)^3$ after 10^{14} particles/cm^2



Summary: Key scientific results

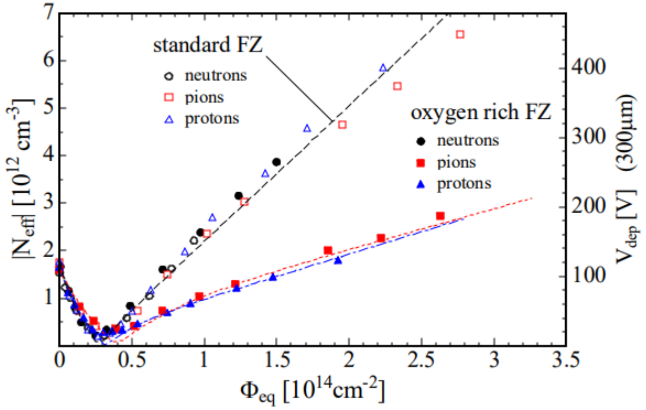
- **Macroscopic Damage Effects**
  - **Leakage current** damage parameter is material independent (no impurity, resistivity or conduction type dependence)
  - Effective doping changes can be improved by oxygenation of the material (**factor 3 for stable damage parameter g_c**). Such improvement is only observed when the radiation environment contains a significant charged particle component.
  - **Reverse annealing saturates** at high fluences (2×10^{14}p/cm^2) for oxygen enriched silicon. **Time constant larger by a factor of 2-4** allowing detectors to remain at temperature for longer periods during maintenance periods: **additional safety m**

- **Damage at the Microscopic Level / Simulations**
  - **Reverse annealing** and **leakage current** are **linked to defect clusters**
  - Correlations between microscopic defects and macroscopic parameters found
  - **Charged particle irradiation produces more point defects** than irradiation wit reactor energy neutrons
  - **Defect kinetics models** and device models can **predict macroscopic behavior qualitatively. However, some model predictions have to be proved.**



Oxygen and standard silicon
- Particle dependence -

23 GeV protons - 192 MeV pions - reactor neutrons



- Strong improvement for pions and protons
- Almost no improvement for neutrons ⇒ "Proton-Neutron-Puzzle"

Summary: Key technological results

DOFZ – Diffusion Oxygenated Float Zone

♦ Oxygen enrichment

- Many oxygenation techniques tested. Final solution: Diffusion of oxygen from Si/SiO_2-interface using high temperature drive in (1150°C in Quartz, up to 1200°C in SiC-tube), method applicable for any wafer as part of normal process.
- Diffusion Technology has been successfully transferred to several silicon detector manufacturers (SINTEF, Micron, ST, CiS, ..) and full-scale microstrip detectors produced.

♦ Quality of DOFZ-detectors vs. standard process:

- Diffusion Oxygenated Float Zone wafers produce detectors which prior to irradiation are no different to those produced on standard material.
- Irradiated standard and oxygenated test structures show **same increase in interface generation current and oxide charges**.
- **Trapping:** Up to a fluence of 2 x 10^{14} cm^2 (24GeV/c p) **no difference** between DOFZ and FZ observed (ATLAS strip detector).

Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment
ELSEVIER
Volume 466, Issue 2, 1 July 2001, Pages 308-326

Radiation hard silicon detectors—developments by the RD48 (ROSE) collaboration

G Lindström [a], M Ahmed [b], S Albergo [c], P Allport [d], D Anderson [e], L Andricek [f], M.M Angarano [g], V Augelli [h], N Bacchetta [i], P Bartalini [g], R Bates [j], U Biggeri [k], G.M Bilei [g], D Bisello [i], D Boemi [c], E Borchi [k], T Botila [l], T.J Brodbeck [m], M Bruzzi [k], T Budzynski [n]…D Žontar [q]

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https://doi.org/10.1016/S0168-9002(01)00560-5

Abstract

The RD48 (ROSE) collaboration has succeeded to develop radiation hard silicon detectors, capable to withstand the harsh hadron fluences in the tracking areas of LHC experiments. In order to reach this objective, a defect engineering technique was employed resulting in the development of Oxygen enriched FZ silicon (DOFZ), ensuring the necessary O-enrichment of about 2×10^{17} O/cm^3 in the normal detector processing. Systematic investigations have been carried out on various standard and oxygenated silicon diodes with neutron, proton and pion irradiation up to a fluence of $5\times10^{14}cm^{-2}$ (1 MeV neutron equivalent). Major focus is on the changes of the effective doping concentration (depletion voltage). Other aspects (reverse current, charge collection) are covered too and

Towards a new COLLABORATION : RDXX

1st Workshop on Radiation hard semiconductor devices for very high luminosity colliders CERN 28-30 November 2001

[1st Workshop on Radiation hard semiconductor devices for very high luminosity colliders at CERN -- 28-30 November 2001]

==

First Announcement of the "1st Workshop on Radiation Hard Semiconductor Devices for Very High Luminosity Colliders"
held at CERN, 28-30 November 2001
http://cern.ch/ssd/

==

The detector developments for the Large Hadron Collider (LHC) at CERN have pushed the present day tracking detectors to the very edge of the current detector technology with respect to radiation hardness and readout speed. However, in future high luminosity hadron colliders the innermost semiconductor-based particle trackers will face even higher radiation levels with charged hadron fluences well above 5x10^{15} particles/cm^2.
So far only few experiments have been performed in this fluence range and it seems obvious that the present-day technology has to be improved with respect to radiation tolerance in order to be fully operational in future colliders.

Cinzia, Christian, Michael



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Workshop topics:

- High luminosity colliders and their requirements
- New device structures
- Defect engineered silicon
- Operational conditions
- Other semiconductor detectors
- Simulations

===

What's New ?

- ❑ P-type Si
- ❑ Cz Si
- ❑ Thin sensors
- ❑ 3D (columnar sensors)
- ❑ (WBG) SiC, GaN

Silicon 3D radiation sensors: general characteristics; irradiation test results

Sherwood Parker and Christopher Kenney (LBL Berkeley,USA)

1^{st} Workshop on
Radiation hard semiconductor devices for very high luminosity colliders
CERN
28-30 November 2001

Silicon Radiation Sensors with Three Dimensional Electrode Arrays

1. Detects ionization in Intrinsic silicon that has been depleted of normal mobile charge carriers by back-biased P^+ and N^+ electrodes BUT

2. Unlike normal planar PIN diodes with electrodes confined to the silicon surfaces, these penetrate through the substrate, and can be closely spaced.

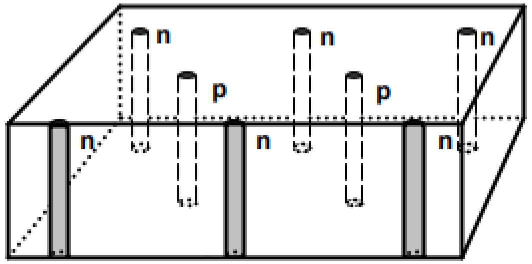
3. This provides order-of-magnitude faster signals and order-of-magnitude greater resistance to the damaging effects of bulk radiation damage.

4. In addition, the fabrication technology allows the edges to be made into electrodes, eliminating the large dead region around the saw-cut edges of standard planar diodes.

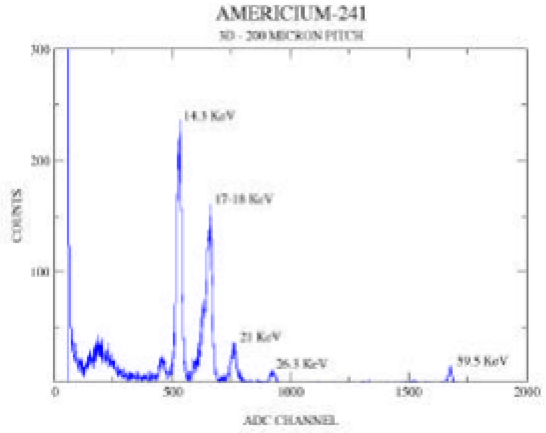
5. This active-edge technology permits large areas to be covered with modest size sensors that can be made with high yield, and without dead bands along their borders, something of great importance in medicine and biology.

Sherwood Parker and Christopher Kenney
University of Hawaii

Nucl. Instr. Meth. A 395 (1997) 328,
Trans. Nucl. Sci. 46 (1999) 1224; 48 (2001) 189,1629;
See authors for page proofs of preliminary paper on active edges.



Simplified Cross Section of Part of Sensor

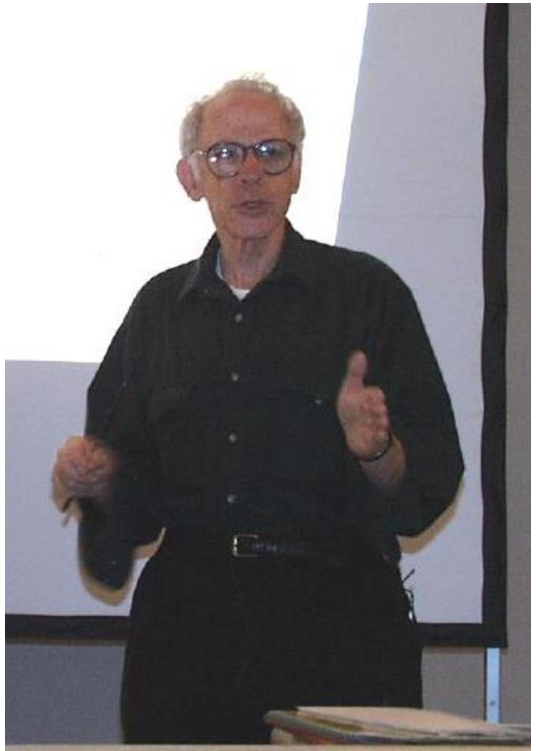


Am ^{241} Spectrum Recorded With 3D Sensor

ELSEVIER
Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment
Volume 395, Issue 3, 21 August 1997, Pages 328-343

3D — A proposed new architecture for solid-state radiation detectors ☆

S.I. Parker [a], C.J. Kenney [a], J. Segal [b]



THIN SENSORS

NOISE LEVEL & THRESHOLD in PIXELS COMPATIBLE with SMALL SIGNALS ~3000 e-h

OTHER COMPONENTS ALSO LOW MASS mechanics, cooling

THIN SENSOR IMPROVES PRECISION less scattering

better aspect ratio

fewer photon conversions

THIN Si SENSORS RADHARD

LOWER DEPLETION VOLTAGE

SHORT DISTANCE CHARGE COLLECTION

SMALL VOLUME - LOWER DARK CURRENT

LOW RESISTIVITY - LATE INVERSION

1st Workshop on
Radiation hard semiconductor devices for very high luminosity colliders
CERN
28-30 November 2001

Submitted to "Radiation Effects" CERN/D.Ph.II/BEAM 75-3
4 September 1975

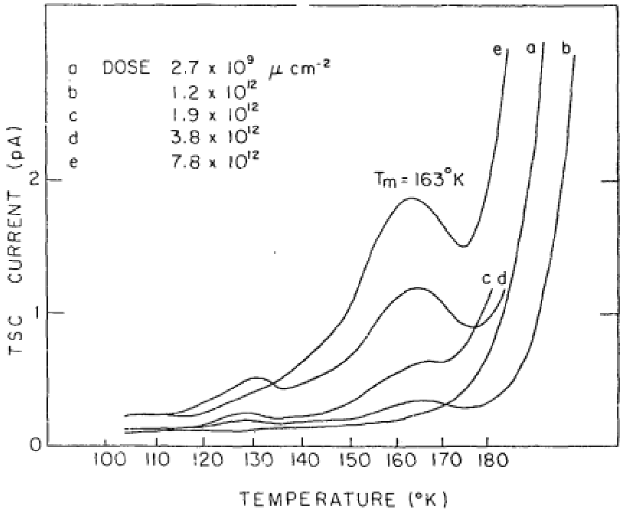
TSC DEFECT LEVEL IN SILICON PRODUCED BY IRRADIATION WITH MUONS OF GeV-ENERGY

E.H.M. Heijne
CERN, Geneva

J.C. Muller and P. Siffert
Laboratoire de Physique des Rayonnements et d'Electronique Nucleaire, 67037 Strasbourg, France

ABSTRACT

Thermally stimulated current (TSC) measurements on n-type silicon, that is irradiated with high energy muons show the introduction of a defect with energy level 0.40 eV and an introduction rate of .2 cm^{-1}.



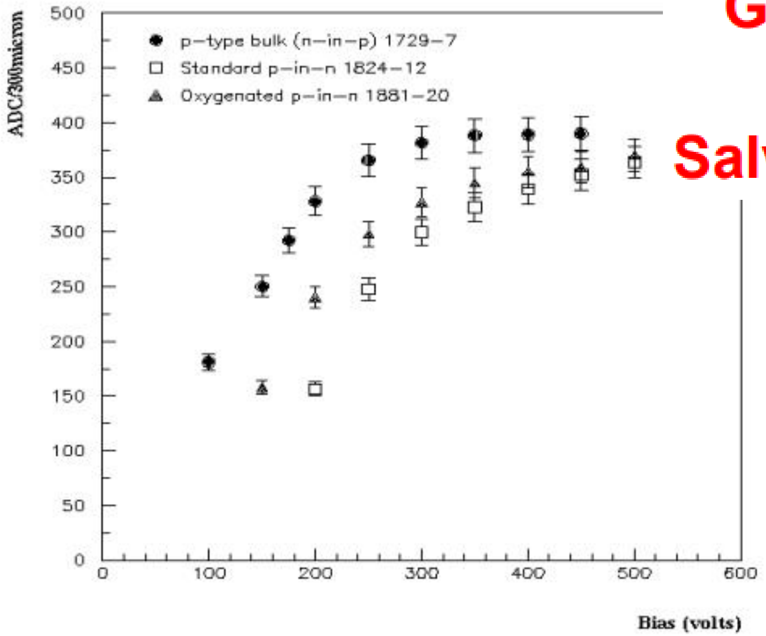
The **2017 High Energy and Particle Physics Prize** of the EPS for an outstanding contribution to High Energy Physics is awarded to **Erik H.M. Heijne**, **Robert Klanner**, and **Gerhard Lutz** *"for their pioneering contributions to the development of silicon microstrip detectors that revolutionised high-precision tracking and vertexing in high energy physics experiments."*

Aspects of CCE in irradiated silicon detectors and advantages using p-type silicon

Gianluigi Casse
Phil Allport
Salva Marti i Garcia

Detectors produced with n-side read-out do suffer from the disadvantage of requiring potentially expensive double-sided processing

Use of p-type substrates does provide a viable alternative where cost is of paramount importance



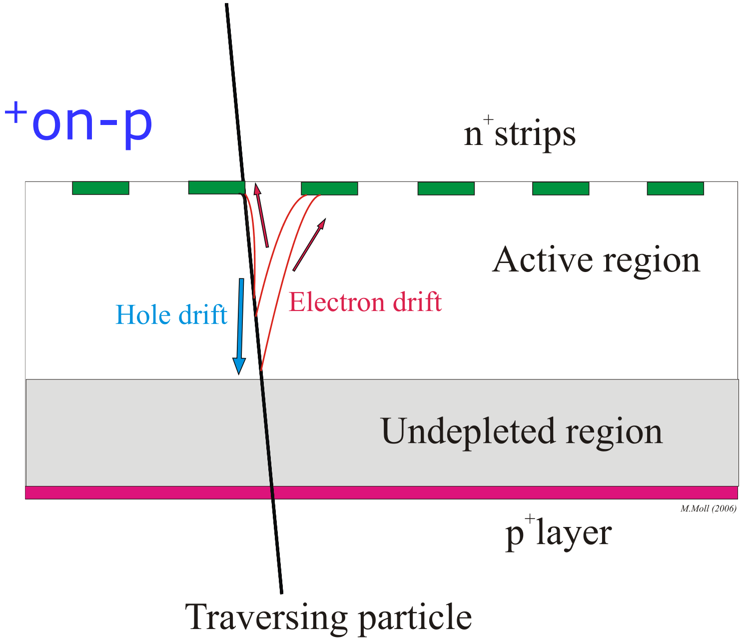
Comparison of p-type and n-type detectors after 3×10^{14} p/cm^2

1st Workshop on Radiation hard semiconductor devices for very high luminosity colliders

1st Workshop on
Radiation hard semiconductor devices for very high luminosity colliders
CERN
28-30 November 2001

p-type silicon after high fluences:

n+on-p



n-on-p silicon, under-depleted:

- Limited loss in CCE
- Less degradation with under-depletion
- Collect electrons (fast)

*reality is more complex (e.g. **double junction**)!*

ELSEVIER
Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment
Volume 476, Issue 3, 11 January 2002, Pages 556-564

The origin of double peak electric field distribution in heavily irradiated silicon detectors ☆

V Eremin [a], E Verbitskaya [a], Z Li [b]

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St. Petersburg 194021, Russia
[b] Brookhaven National Laboratory, Upton, NY 11973-5000, USA

New Semiconductor Materials for Radiation Detectors

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Radiation Imaging Group
Department of Physics
University of Surrey
Guildford, UK

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Summary of some material properties:

	Z	E_G (eV)	W (eV/ehp)	ρ_i at RT (Ω)
Si	14	1.12	3.6	~10^4
Ge	32	0.66	2.9	50
InP	49/15	1.4	4.2	10^7
GaAs	31/33	1.4	4.3	10^8
CdTe	48/52	1.4	4.4	10^9
$CdZn_{0.2}Te$	48/52	1.6	4.7	10^{11}
HgI_2	80/53	2.1	4.2	10^{13}
TlBr	81/35	2.7	5.9	10^{11}
Diamond	6	5	13	>10^{13}

Also: SiC, PbI_2, GaSe

Present Status and Prospects for Radiation Hard CVD Diamond Detectors

Harris Kagan
Ohio State University

on behalf of the RD42 Collaboration
Nov. 30, 2001, CERN

courtesy of DeBeers Industrial Diamond

WBG == no leakage current !!

1st Workshop on Radiation hard semiconductor devices for very high luminosity colliders
CERN
28-30 November 2001

…MCz Si for particle detectors

HELSINKI INSTITUTE OF PHYSICS

Development of Particle Detectors made of Czochralski Grown Silicon

Helsinki Institute of Physics, CERN/EP, Switzerland

Microelectronics Centre, Helsinki University of Technology, Finland

Okmetic Ltd., Finland

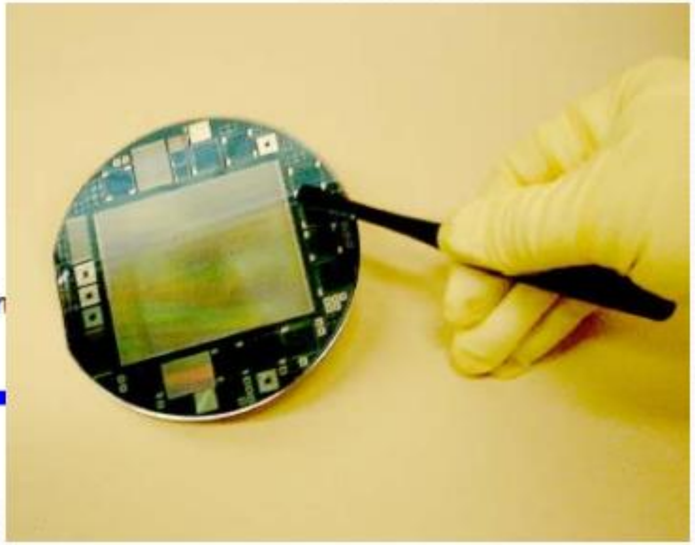
Ioffe PTI, Russia

Brookhaven National Laboratory, USA

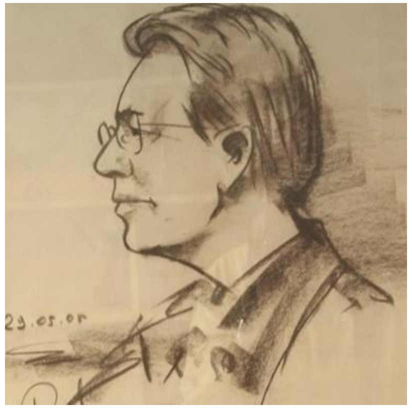
CERN RD39 & RD50

Accelerator Laboratory, University of Jyväskylä, Fin

Eija Tuominen
RD50 Workshop 03.10.2002

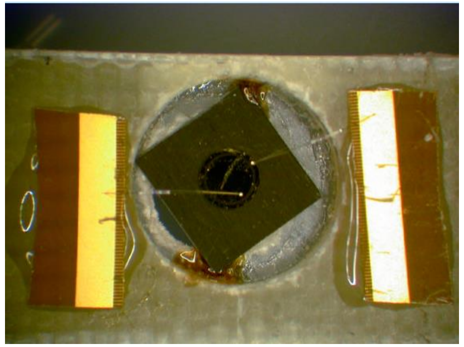


Eija Tuominen



Jaakko Härkönen

Panja Luukka and Jaakko



Epitaxial SiC Schottky barriers for radiation and particle detection

M. Bruzzi, M. Bucciolini, R. D'Alessandro, S. Lagomarsino, S. Pini, S. Sciortino

INFN Firenze - Università di Firenze

F. Nava *INFN Bologna – Università di Modena*

2nd RD50 Workshop CERN, 18-20 May, 2003

Electrical characterization and optimization of silicon carbide p⁺/n junctions for particle detectors

F. Moscatelli (a), A. Scorzoni (a),
Poggi (b), G. C. Cardinali (b) and R. Nipoti (b)
imento d'Ingegneria Elettronica e dell'Informazione,
ità di Perugia, via G. Duranti 93, 06125 Perugia, Italy.
(b) CNR- IMM Sezione di Bologna, via Gobetti 101, 40129 Bologna, Italy.

Università degli Studi di Perugia

IMM Bologn

Property	Diamond	4H SiC	Si
Bandgap [eV]	5.5	3.3	1.12
Breakdown Field [V/cm]	10^7	$4\cdot10^6$	$3\cdot10^5$
Electron mobility [cm^2/Vs]	1800	800	1450
Hole mobility [cm^2/Vs]	1200	115	450
Saturation velocity [cm/s]	$2.2\cdot10^7$	$2\cdot10^7$	$0.8\cdot10^7$
Effective atomic number Z_{eff}	6	~10	14
Dielectric constant ε_r	5.7	9.7	11.9
e-h creation energy [eV]	13	8.4	3.6
minority carrier lifetime [s]	10^{-9}	$5\cdot10^{-7}$	$2.5\cdot10^{-3}$
Wigner Energy [eV]	43	25	13-20

R&D Proposal

LHCC 2002-003
LHCC P6
15 February 2002

DEVELOPMENT OF RADIATION HARD SEMICONDUCTOR

DEVICES FOR VERY HIGH LUMINOSITY COLLIDERS

To develop radiation hard semiconductor detectors that can operate beyond the limits of present devices. These devices should withstand fast hadron fluences of the order of 10^{16} cm^{-2}, as expected for example for a recently discussed luminosity upgrade of the LHC to 10^{35} cm^{-2}s^{-1}.

- **Material engineering**
- **Device engineering**
- **Variation of detector operational conditions**

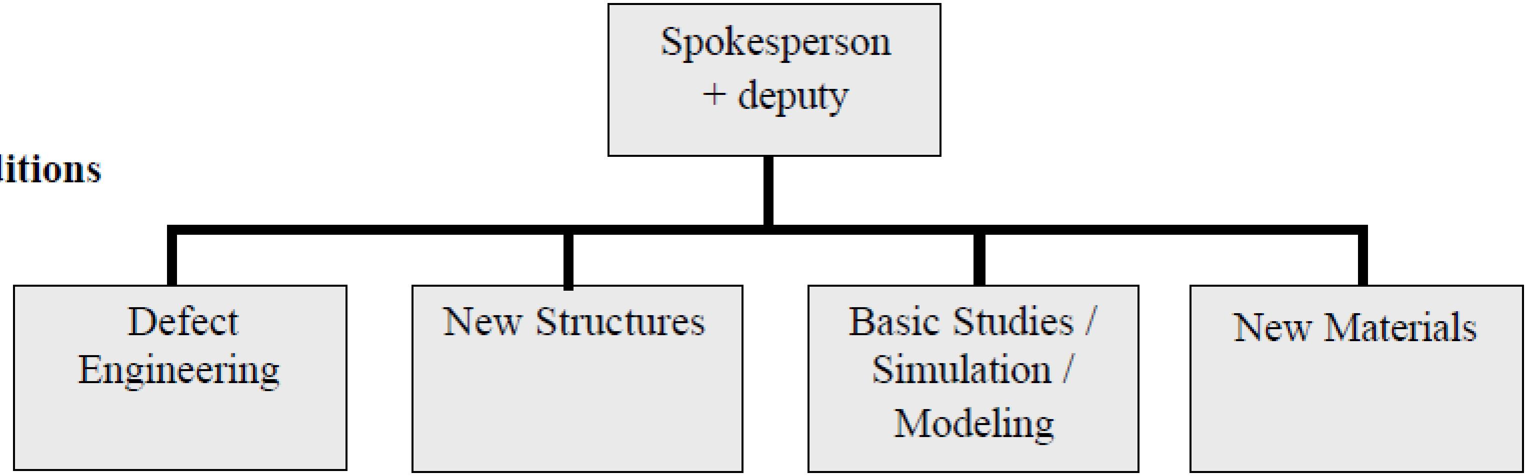


Figure 10: The participating institutes form research teams focused on specific activities. Each team is co-ordinated by a Team Convener.

The RD50 CERN Collaboration

52 Institutes from Europe and USA - ~ 270 participants

- February 2002 proposal submitted to LHCC
- May 2002 : LHCC recommended for approval
- June 2002 : approved by the Research Board

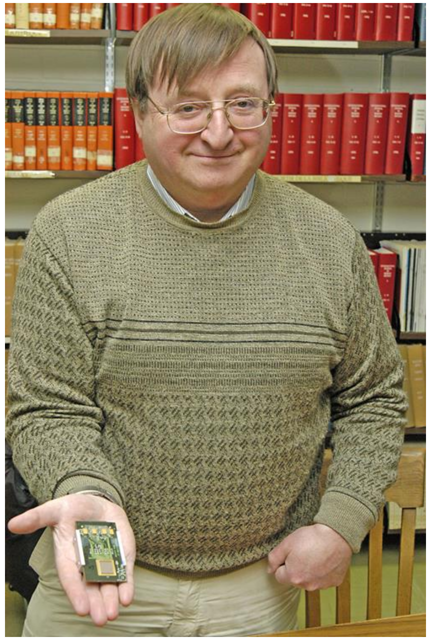
LHCC minutes: “The Committee considers that the proposed experimental programme is sound and that **the results of the R&D would be important for future high luminosity colliders, including an upgraded LHC**.

However, the **Committee asks the Collaboration to present a clearer and simpler organizational structure that will see through the main lines of R&D of the overall programme and that will include the assignments of individuals to particular tasks.** “

Our Proposal for a simpler organization structure

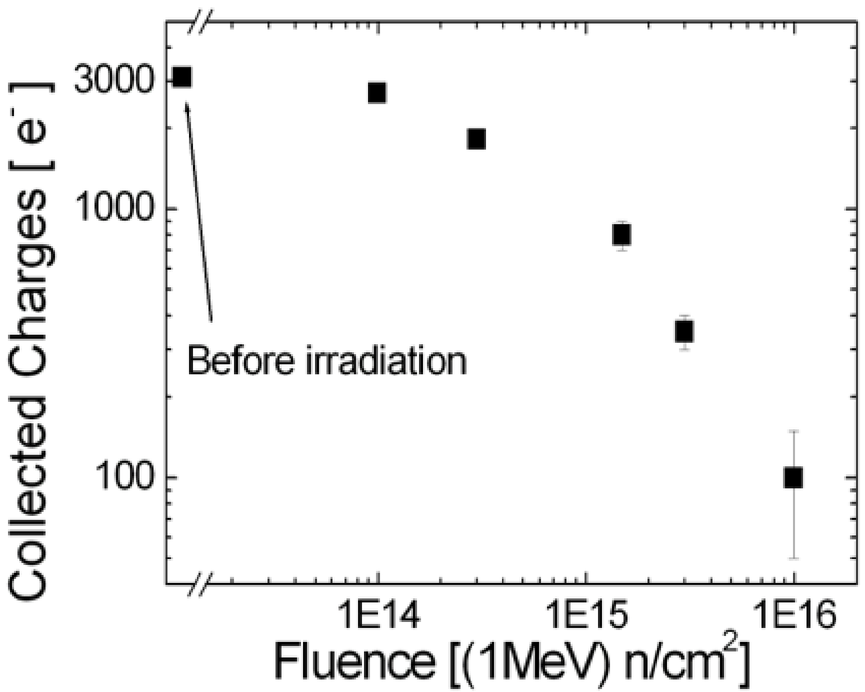
Two major research lines

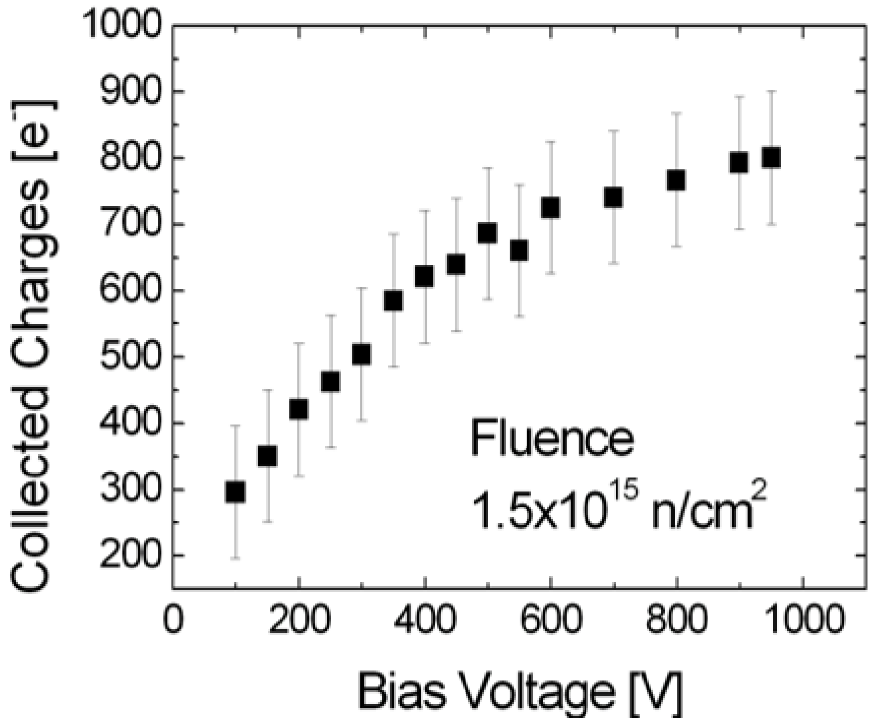
Block 1	Block 2
Material Engineering	**Device Engineering**
Mara Bruzzi **Spokesperson**	**Claude Leroy** **Deputy**
Defect/Material Characterisation B.G.Svensson	Pad Detector Characterisation S. Pospisil
Defect Engineering E. Fretwurst	Full Detectors Systems G. Casse
New Materials J. Vaitkus	New Structures J. Vaitkus



SiC (Data from Moscatelli et al. Rd50 7° Workshop Nov. 2005)

Epi-SiC: CCE 26% (800 e^{-}) after $1.5x10^{15}$ n/cm^2 with epilayer of 50µm.





And from RESMDD05: 300 e^{-} at 600 V after $7x10^{15}$ n/cm^2

S. Sciortino et al. "Effects of heavy proton and neutron irradiations on epitaxial SiC Schottky diodes", NIM A 552 (2005) 138-145.

Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment
Volume 579, Issue 2, 1 September 2007, Pages 754-761

Comparing radiation tolerant materials and devices for ultra rad-hard tracking detectors

2007

Mara Bruzzi [a], Hartmut F.-W. Sadrozinski [b], Abraham Seiden [b]

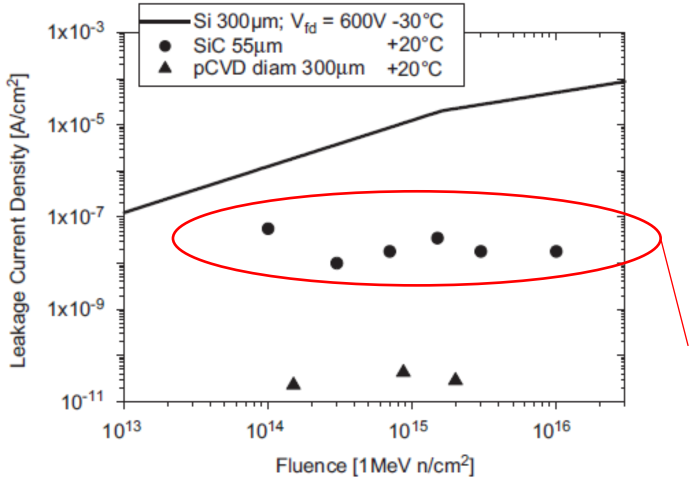


Fig. 2. Typical leakage current density for Si, SiC and diamond as a function of the fluence (1 MeV n equivalent). The SiC device has a thickness of 55 µm, data are redrawn from Ref. [7]. The current density of the Si device (300 µm thick) has been calculated using Eqs. (1) and (2) at −30 °C and considering a maximum applied voltage of 600 V. The knee observed around a fluence of 2×10^{15} cm^{-2} occurs when the detector ceases to be fully depleted. Data for polycrystalline CVD diamond (300 µm thick) are taken after pumping the device with a ^{60}Co source at 300 K [8].

SiC

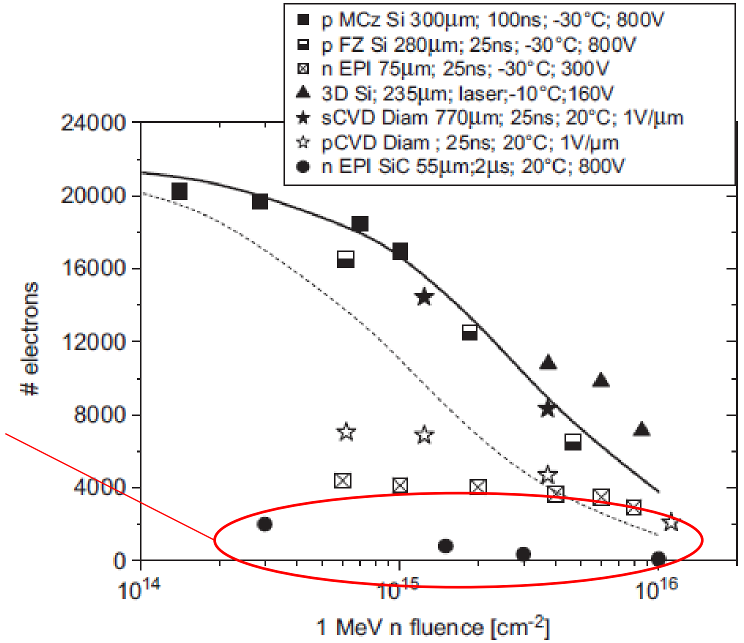
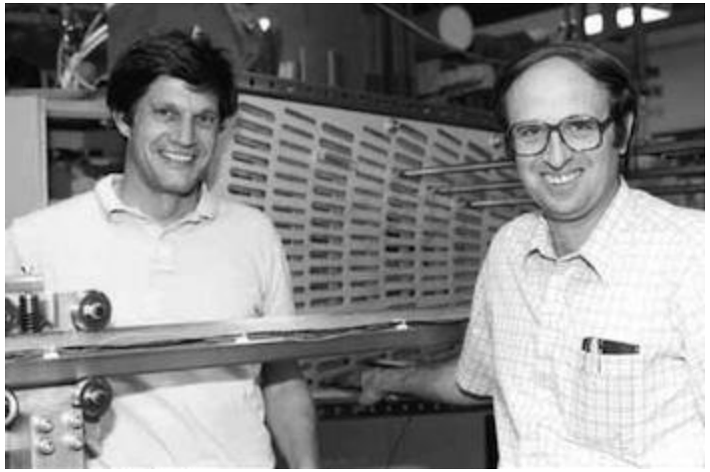


Fig. 4. Collected charge with different materials after irradiation with fast hadrons up to the fluence of 10^{16} cm^{-2} redrawn from Refs. [3,15,18–20]. The two curves are simulations employing different trapping constants: 5.1×10^{-16} cm^2/ns (broken line) and 1.8×10^{-16} cm^2/ns (solid line), respectively.



Abe Seiden and Hartmut Sadrozinski from the SCIPP archives

Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment
Volume 730, 1 December 2013, Pages 226-231

Ultra-fast silicon detectors

H. F.-W. Sadrozinski [a], S. Ely [a], V. Fadeyev [a], Z. Galloway [a], J. Ngo [a], C. Parker [a], B. Petersen [a], A. Seiden [a], A. Zatserklyaniy [a], N. Cartiglia [b], F. Marchetto [b], M. Bruzzi [c], R. Mori [c], M. Scaringella [c], A. Vinattieri [c]

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2013

Abstract

We propose to develop a fast, thin silicon sensor with gain capable to concurrently measure with high precision the space (~10µm) and time (~10ps) coordinates of a particle. This will open up new application of silicon detector systems in many fields. Our analysis of detector properties indicates that it is possible to improve the timing characteristics of silicon-based tracking sensors, which already have sufficient position resolution, to achieve four-dimensional high-precision measurements. The basic sensor characteristics and the expected performance are listed, the wide field of applications are mentioned and the required R&D topics are discussed.

2006

In-one

RD50 Scientific Organization of RD50

Development of Radiation Hard Semiconductor Devices for High Luminosity Colliders

Spokespersons
Mara Bruzzi, Michael Moll
INFN Florence, CERN ECP

Defect / Material Characterization	Defect Engineering	New Materials	Pad Detector Characterization	New Structures	Full Detector Systems
Bengt Svensson (Oslo University)	*Eckhart Fretwurst* (Hamburg University)	*E. Verbitskaya* (Ioffe St. Petersburg)	*G. Kramberger* (Ljubljana)	*R. Bates* (Glasgow University)	*Gianluigi Casse* (Liverpool University)
Characterization of microscopic defects • properties of standard-, defect engineered and new materials pre- and post-irradiation	Defect engineered silicon: • Epitaxial Silicon • CZ, MCZ • Other impurities H, N, Ge, … • Thermal donors • Pre-irradiation • Oxygen Dimer	Development of new radiation tolerant materials: • SiC • GaN •other materials	• Test structure characterization IV, CV, CCE • NIEL • Device modeling • Common irrad. • Standardization of measurements	Evaluation of new detector structures • 3D detectors • Thin detectors • Cost effective solutions • Semi 3D	•LHC-like tests •Links to HEP •Links to R&D on electronics •Comparison: pad-mini-full detectors • Pixel group

- 2006: Research Line "New Materials" suppressed
  - R&D performed by RD50 on **SiC and GaN did not show promising results**
  - Activity within RD50 reduced on Working Group level to conclude the started work program

RD50

RD50 Organizational Structure

Co-Spokespersons

Gianluigi Casse and *Michael Moll*

(Liverpool University) (CERN PH-DT)

Defect / Material Characterization
Ioana Pintilie
(NIMP Bucharest)

- Characterization of microscopic properties of standard-, defect engineered and new materials pre- and post-irradiation
- DLTS, TSC, ….
- SIMS, SR, …
- NIEL (calculations)
- WODEAN: Workshop on Defect Analysis in Silicon Detectors (G.Lindstroem & M.Bruzzi)

Detector Characterization
Eckhart Fretwurst
(Hamburg University)

- Characterization of test structures (IV, CV, CCE, TCT,.)
- Development and testing of defect engineered silicon devices
- EPI, MCZ and other materials
- NIEL (experimental)
- Device modeling
- Operational conditions
- Common irradiations
- Wafer procurement (M.Moll)
- Device Simulations (V.Eremin)

New Structures
Giulio Pellegrini
(CNM Barcelona)

- 3D detectors
- Thin detectors
- Cost effective solutions
- Other new structures
- Detectors with internal gain (avalanche detectors)
- Slim Edges

- 3D (R.Bates)
- LGAD (V.Greco)
- Slim Edges (Vitaliy Fadeyev)

Full Detector Systems
Gregor Kramberger
(Ljubljana University)

- LHC-like tests
- Links to HEP
- Links electronics R&D
- Low rho strips
- Sensor readout (Alibava)
- Comparison:
  - pad-mini-full detectors
  - different producers
- Radiation Damage in HEP detectors

- Test beams (M.Bomen & G.Casse)

Collaboration Board Chair & Deputy: G.Kramberger (Ljubljana) & J.Vaitkus (Vilnius), Conference committee: U.Parzefall (Freiburg)
CERN contact: M.Moll (PH-DT), Secretary: V.Wedlake (PH-DT), Budget holder & GLIMOS: M.Glaser (PH-DT)

Last (43rd) RD50 Workshop on Radiation Hard Semiconductor Devices for Very High Luminosity Colliders (CERN)

[RD50 Workshops (cern.ch)](https://cern.ch)

28 novembre 2023 a 1 dicembre 2023
CERN
Europe/Zurich fuso orario

Cheers from old fellows looking forward to enjoy future collaboration together !

May/June 10	16th RD50	16th RD50 - Workshop on Radiation hard semiconductor devices for very high luminosity colliders, Barcelona, 31 May-2 June 2010
November 09	15th RD50	15th RD50 - Workshop on Radiation hard semiconductor devices for very high luminosity colliders, CERN, 16-18 November, 2009
June 09	14th RD50	14th RD50 - Workshop on Radiation hard semiconductor devices for very high luminosity colliders, Freiburg, 3-5 June, 2009
November 08	13th RD50	13th RD50 - Workshop on Radiation hard semiconductor devices for very high luminosity colliders, CERN, 10-12 November, 2008
June 08	12th RD50	12th RD50 - Workshop on Radiation hard semiconductor devices for very high luminosity colliders, Ljubljana, Slovenia, 2-4 June, 2008
November 07	11th RD50	11th RD50 - Workshop on Radiation hard semiconductor devices for very high luminosity colliders, CERN, 12-14 November, 2007
June 07	10th RD50	10th RD50 - Workshop on Radiation hard semiconductor devices for very high luminosity colliders, Vilnius, Lithuania, 4-6 June, 2007
October 06	9th RD50	9th RD50 - Workshop on Radiation hard semiconductor devices for very high luminosity colliders, CERN, 6-8 October, 2006
August 06	Hamburg Meeting	RD50 workshop on defect analysis in radiation damaged silicon detectors, University of Hamburg (DESY site), 23/24-August 2006
June 06	8th RD50	8th RD50 - Workshop on Radiation hard semiconductor devices for very high luminosity colliders, Prague, Czech Republic, 25-28 June 2006
November 05	7th RD50	7th RD50 - Workshop on Radiation hard semiconductor devices for very high luminosity colliders, CERN, 14-16 November, 2005
June 05	6th RD50	6th RD50 - Workshop on Radiation hard semiconductor devices for very high luminosity colliders, Helsinki, Finland, 2-4 June, 2005
February 05	Trento Meeting	RD50 - Full Detector Systems - Meeting, Trento, Italy, 28 February 2005
October 04	5th RD50	5th RD50 - Workshop on Radiation hard semiconductor devices for very high luminosity colliders, Florence, Italy, 14-16 October, 2004
May 04	4th RD50	4th RD50 - Workshop on Radiation hard semiconductor devices for very high luminosity colliders, CERN, 5-7 May, 2004
November 03	3rd RD50	3rd RD50 - Workshop on Radiation hard semiconductor devices for very high luminosity colliders, CERN, 3-5 November, 2003
May 03	2nd RD50	2nd RD50 - Workshop on Radiation hard semiconductor devices for very high luminosity colliders, CERN, 18-20 May, 2003
October 02	1st RD50	1st RD50 - Workshop on Radiation hard semiconductor devices for very high luminosity colliders, CERN, 2-4 October, 2002
November 01	R&D Worskhop	1st RD50 - Workshop on Radiation hard semiconductor devices for very high luminosity colliders, CERN, 28-30 November, 2001