Present and future of the SIRAD irradiation facility at the INFN National Laboratory of Legnaro (Padova, Italy)

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When the SIRAD irradiation facility started …

The facility was initially running in 1998 for bulk damage studies in silicon detectors for High Energy Physics applications in the framework of the RD48 CERN Collaboration by proton irradiation.

The facility was then considered in 2000 for SEE studies in microelectronics devices for Space application in collaboration with DEI (Univ. Padova) and DIMSAT (Univ. Cassino) by ion irradiation.

The facility has been equipped with funds from:
- Physics Departments, Univ. Padova
- INFN Section of Padova
- INFN National Laboratory of Legnaro.
SIRAD Collaboration in Italy and abroad (2001-2004)

1) Dip. Fisica and INFN Padova
2) INFN Laboratori Nazionali di Legnaro
3) Dip. Ingegneria dell'Informazione, Padova
4) Tecnomare SpA (Venezia)
5) Center for Advance Space Optics (Trieste)
6) Dip. Fisica and INFN, Trieste
7) ITC-IRST (Trento)
8) Dip. Informatica e Telecomunicazioni, Trento
9) INAF, Sezione di Milano
10) ST Microelectronics (Agrate Brianza, Milano)
11) Dip. Elettronica, Pavia
12) Dip. Ingegneria Industriale, Bergamo
13) Dip. Fisica Sperimentale, Torino
14) Dip. Automatica e Informatica, Politecnico di Torino
15) Dip. Fisica and INFN, Bologna
16) Dip. Energetica and INFN, Firenze
17) Aurelia Microelettronica SpA (Viareggio)
18) Dip. Ingegneria Elettronica, Università Roma 2
19) INAF, Sezione di Roma
20) DAEIMI and DSM, Università di Cassino
21) ST Microelectronics (Catania)

A) Institut für Experimentalphysik (Hamburg, Germany)
B) LETI (Grenoble, France)
C) Centro Nacional de Microelectronica (Barcellona, Spain)
D) IMEC (Louvain, Belgium)
E) Philips Semiconductor (Nijmegen, Netherlands)
F) CERN (Geneve, Switzerland)
G) Helsinki Institute of Particle Physics (Finland)
H) Santa Cruz Institute for Particle Physics (California, U.S.A)
Beam time allocation at SIRAD in 2001-2004

(2179 hours => 91 days)

- 1) CMOS and Bipolar technologies: 7%
- 2) Bulk damage in silicon detectors: 12%
- 3) Secondary Electron Emission and IEEM: 10%
- 4) SEB and SEGR in power devices: 28%
- 5a) SEE in Memories: 7%
- 5b) SEE in FPGA: 14%
- 5c) SEE in ASIC and COTS: 21%
- 6) Others: 1%

January 2001 - December 2004 (2179 hours, 91 days)
The SIRAD irradiation facility

The SIRAD irradiation facility is located at the Tandem accelerator of the INFN National Laboratory of Legnaro (Padova, Italy).

**Tandem accelerator:**
- Van de Graaff type;  **15 MV maximum voltage**; two strippers;
- servicing 3 experimental halls for nuclear and interdisciplinary Physics.

Schematics of the 15 MV **Tandem Van de Graaff accelerator** and of the **SIRAD irradiation facility** at the +70° beam line (left). A photograph of the SIRAD irradiation facility is also shown for completeness (right).
Typical ion species available at the Tandem accelerator

- **Ion species** from $^1$H (22-30 MeV) up to $^{197}$Au (1.4 MeV/a.m.u.)
- **LET** from $0.02$ MeV×cm$^2$/mg ($^1$H) up to $79.1$ MeV×cm$^2$/mg ($^{197}$Au)

The energy values refer to the most probable $q_1$ and $q_2$ charge state, with two stripper stations and the Tandem operating at 14 MV.

<table>
<thead>
<tr>
<th>Ion Species</th>
<th>$q_1$</th>
<th>$q_2$</th>
<th>Energy (MeV)</th>
<th>Range in Si (µm)</th>
<th>Surface LET in Si (MeV×cm$^2$/mg)</th>
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1st multi-source

2nd multi-source
High flux (>10⁸-10⁹ ions/cm²×s) irradiation set-up on 5×5 cm² area

The on-line beam monitoring for rastered proton and ion beams by the 3×3 battery of Faraday cups positioned behind the DUT: side view of the experimental setup. The aperture of each Faraday cup is 0.6×0.6 cm². The figure is not drawn to scale.
Low flux ($\approx 10^2$-$10^5$ ions/cm$^2$×s) irradiation set-up on 2×2 cm$^2$ area

The on-line beam monitoring system for defocused beams by the fixed and mobile diodes:
- left: side view of the experimental set-up;
- right: front view (transverse to the beam) of the fixed and mobile diode boards.

The mobile diodes are mounted on the sample holder with the DUT. The figure is not drawn to scale.
Sample holder

Sample holder: 10.2 cm (horizontal) $\times$ 33 cm (vertical) with M3 screws to fix the boards

The sample holder is vertically motorized in order to irradiate more samples without breaking the vacuum: the zone for user irradiation has a vertical amplitude of 19 cm

The boards on the sample holder including the connectors have to be inscripted in a 14 cm diameter
How to access the SIRAD irradiation facility

The time for tests/experiments is assigned on the basis of a scientific proposal evaluated by the LNL User Selection Panel (USP) two times each year:
- June for the period October-February (1\textsuperscript{st} semester)
- January for the period March-July (2\textsuperscript{nd} semester)

All the proposed activities for the SIRAD irradiation facility are grouped in one unique proposal submitted to USP. The assigned time is shared among the different proposed activities depending on the necessities/priorities.

Advantages:
- No charge for the approved activities;
- Possibility of free access to the LNL facilities and services (mechanical workshop, user and radioprotection services, guest house).

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Fax:+39-049-8277237
Web site: http://sirad.pd.infn.it/
Beam time shift: details

Irradiation beam time shift: **24-48 hours**, eventually to be shared among more groups depending on the requirements.

Personal support: **2 operators** for running the Tandem accelerator
1 person for running the SIRAD facility (if requested by users)

Time required for beam setting: **2 hours for each ion species** (average value)
6 ion species are routinely considered in 24 hours

Required vacuum level: **2-3×10^{-5} mbar**
Pumping system: **scroll** pump for pre-vacuum + **turbo** pump for high vacuum
Time required for vacuum: **30 minutes to few hours**, depending on the material budget
Electrical connections and set-up

Possibility to see/illuminate the DUT: yes by a glass window

Electrical connectors on the chamber: 16 BNC + 8 High Voltage BNC (or 24 BNC)
2 connectors DSUB with 50 pin

Experimental set-up: DAQ with remote PC close to the SIRAD beam line and control PC in the user box

Connections SIRAD beam line - user box: 3 network cables for computers
20 BNC connections 50 Ohm
1 video cable 75 Ohm
Next future upgrade for the end of 2005: the irradiation chamber

Shape: cylinder
Dimensions: L=80 cm, D=80 cm
Manufacturer: RIAL Vacuum
Next future upgrade for the end of 2005: motorization of the sample holder

- **High vacuum motors** (free air - $10^{-7}$ mbar operation) from PI (Germany)
- 4 axis of freedom: $X$, $Y$, $Z$, rotation
- **Resolution on motor position** better than 10 µm
- Full compatibility with SIRAD and ESA sample holders

$\Delta X = \pm 150$ mm
$\Delta Y = \pm 75$ mm
$\Delta Z = \pm 25$ mm
$\Delta \theta = \pm 90^\circ$
Tandem–ALPI complex

\[ E_{\text{Tandem-ALPI}} = E_{\text{Tandem}} + E_{\text{ALPI}} = E_{\text{Tandem}} + Q_{\text{Tandem}} \times 35 \text{ MeV} \]
### Comparison Tandem accelerator and Tandem-ALPI complex

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<tr>
<th>Ion Species</th>
<th>q₁</th>
<th>q₂</th>
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Andrea Candelori - The SIRAD Irradiation Facility at LNL (Padova, Italy) – http://sirad.pd.infn.it
**The Ion Electron Emission Microscope (IEEM)**

- **223 MeV Br ion beam**
- **Purpose:** Single Event Effect mapping

**Lattice details:**
- Lattice step: 40 µm
- Structure width is about 6 µm
- The lattice is made by copper
- Sub-µm sample holder
Conclusions

• The SIRAD irradiation facility at the 15 MV TANDEM accelerator:
  - Ion species from $^1$H (23-30 MeV) up to $^{197}$Au (1.4 MeV/a.m.u.)
  - LET from 0.02 MeV$\times$cm$^2$/mg up to 79.1 MeV$\times$cm$^2$/mg
  - High (>10$^8$-10$^9$ ions/cm$^2\times$s) and low (10$^2$-10$^5$ ions/cm$^2\times$s) flux set-up
  - New irradiation chamber and sample holder (compatible with ESA standards)
  - Potentiality to increase the ion energy of $Q_{\text{Tandem}}\times35$ by ALPI
  - Ion Electron Emission Microscopy capability

• The 7 MV CN accelerator:
  - Monochromatic neutron spectra: D(d,n)$^3$He, T(d,n)$^4$He, $^7$Li(p,n)$^7$Be
  - Continuous neutron spectra: $^9$Be(d,n)$^{10}$B
  - Thermal neutrons: $^9$Be(d,n)$^{10}$B with moderator

• Total dose tests:
  - X-rays: W (L-lines at 7-12 keV) and Mo (K-lines at 17-20 keV) anode;
    dose rate: 120 rad(Si)/s.
  - $\gamma$-rays: $^{60}$Co source with 1-5 rad(Si)/s dose rate (D=20-45 cm).
### CN accelerator: neutron beams

#### Table II

<table>
<thead>
<tr>
<th>Formula</th>
<th>$E_{\text{beam}}$ (MeV)</th>
<th>$I_{\text{max}}$ (nA)</th>
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<th>$E_{\text{neutrons at } 0^\circ}$ (MeV)</th>
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with moderator

![Graph showing neutron energy and particle energy](image)

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