SiC within INFN: status and perspectives

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SiC properties

- SiC sensors suited for:
  - room/high-temperature and harsh environment detector operation;
  - UV photon detection (visible-blind)
- Characteristics:
  - Wide bandgap energy ($E_g \approx 3.27$ eV)
  - High breakdown electric field (3 MV cm^{-1})
  - High carrier saturation drift velocity (2×10^7 cm s^{-1})
  - High displacement atom energy (22 – 35 eV)

Comparison between SiC and other semiconductors properties

Table 1. Comparison of properties of selected important materials mostly used for radiation ionizing detector realization with semiconductor 4H–SiC. Data compiled from [14, 23–25] and references therein.

Property	D	Si	Ge	GaAs	CdTe	4H–SiC
Bandgap (eV)	5.5	1.12	0.67	1.42	1.49	3.27
Relative dielectric constant	5.7	11.9	16	13.1	10	9.7
Breakdown field (MV cm^{-1})	10	0.3	0.1	0.4	0.5	3.0
Density (g cm^{-3})	3.5	2.3	5.33	5.3	5.9	3.2
Atomic number Z	6	14	32	31–33	48–52	14–6
e–h creation energy (eV)	13	3.6	2.95	4.3	4.42	7.78
Saturated electron velocity (10^7 cm s^{-1}) at 300 K	2.2	1.0	0.6	1.2	1.0	2
Electron mobility (cm^2 V^{-1} s^{-1}) at 300 K	1800	1300	3900	8500	1100	800
Hole mobility (cm^2 V^{-1} s^{-1}) at 300 K	1200	460	1900	400	100	115
Threshold displacement energy (eV)	40–50	13–20	16–20	8–20	6–8	22–35
Minimum ionizing energy loss (MeV cm^{-1})	4.7	2.7	6	5.6		4.4

From F. Nava et al., Meas. Sci. Technol. **19** (2008) 102001

SiC as detector material

- Potential of SiC as radiation detector has been long recognized:
  - First SiC neutron detectors > 50 years ago (*Babcock et al. 1957; Babcock & Chang 1962)*
- Poor material properties of the SiC available at that time and lack of adequate investment have hindered the development of the technology for detector fabrication until the 90ies.
- Effort concentrated on improving the properties of SiC by reducing defects produced during the crystal growing process (dislocations, micropipes, etc.) → availability of much higher quality SiC semiconductor materials
  - A parallel effort resulted in improved SiC electronics fabrication techniques

SiC@INFN

- Currently, two initiatives within INFN – CSN5
- ClasSiC (P. Lenzi, grant for young researchers 2015)
  - Dual read-out hadronic calorimetry
  - TOF-PET with sensitivity to Cherenkov light (10 ps resolution)
  - Need for single-photon sensitivity
    - Final target: device with intrinsic amplification (10^3 – 10^4)
- SiCILIA (S. Tudisco, financed as CSN5 "call" 2016)
  - SiC as material for rad-hard detectors in nuclear physics (clear motivating physics case)
    - SiC ΔE-E telescope for ion identification and spectroscopy)
    - Need for unprecedented active volume thickness
    - Large production of large area (cm^2) devices
    - Industrial impact

IFD2015 (Torino, 16-18/12/2015)

- Bring together the vast INFN community involved in detector technology development: many achievements/efforts can be extremely useful for applications different from the starting one;
  - Times have changed (and available resources too): we cannot afford anymore duplications of R&D…
- Some strategic elements have emerged:
  - Collaboration with the industries
  - Collaboration with other Research Institutes
  - Preservation and development of the know-how and transmission to the next generations.

Collaboration with other Research Institutes/Communities

- New technologies require collaborations
  - Some technologies are in our hands, others are not
  - Even for “our” technologies, cross-collaboration and knowledge amongst the community is crucial (e.g. this workshop)

CLASSiC and SiCILIA

Investigate SiC detectors from complementary points of view

CLASSiC		SiCILIA
Light detection	Applications	Particles detection
- Complex p-n junction - Multi-layer - ion implantation	Junction	- Schottky - epitaxial p-n
Thin substrates	Substrate	Thick, high purity substrates
In house CNR-IMM (with opportunistic use of ST facilities)	Manufacturing	P-n junctions @ ST Schottky @ FBK

P. Lenzi, IFD2015 Workshop

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SiC detectors: perspectives

- In recent years, many groups have been working on SiC R&D for a wide spectrum of applications:
  - Space (especially X-ray detectors for planetary exploration, see e.g. J.E. Lees et al., *Nucl. Instr. and Meth. in Phys. Res.* A 604 (2009) 174)
  - Laser-driven ions (e.g. TOF diagnostics at ELI), see e.g. G. Bertuccio et. al., *Appl. Surf. Sci.* 272 (2013) 128, see also G. Lanzalone's talk
  - Neutron detectors
    - Homeland security (fast n and )
    - Nuclear plants (reactor monitoring, spent fuel monitoring, …)
    - Oil and gas prospections (nuclear geophysics)
    - Activities @ ESS
    - BNCT neutron exposure motoring

Conclusions

- SiC stands out as one of the most promising "future" semiconductor material for radiation detectors fabrication;
- Collaboration with Industry and other Research Institutes is strategic in order to improve the technology and make it available to the INFN research community;
- In this framework, CSN5 strongly supports R&D on SiC technology;
- The rapid pace of SiC detector development and the large number of research groups involved worldwide bode well for the future of SiC detector applications.