Topsil's involvement in NitroSil project

Nitrogen impact on vacancy aggregation in silicon single crystals

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25th RD50 WORKSHOP, CERN GENEVA, Nov. 19-21 2014

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OUTLINE

- Introduction to Topsil's products
  - Topsil in brief
  - Applications, capabilities

- Effect of nitrogen on the properties of Si single crystals

- NitroSil project
  - Scope
  - Topsil's and ITME's assignments

- Summary

MANUFACTURER OF HIGH PURITY SILICON WAFERS

- Specialized manufacturer of ultrapure silicon wafers to the global semiconductor industry
- Focus on premium quality silicon for the most demanding purposes
- Strong in-house silicon competencies and knowledge base - close cooperation with universities and research institutions world wide
- State-of-art technology, facilities and equipment
- Long track record, est. 1959 - long term customer relations
- Staff of 350 people, turnover of $58 million (2013)

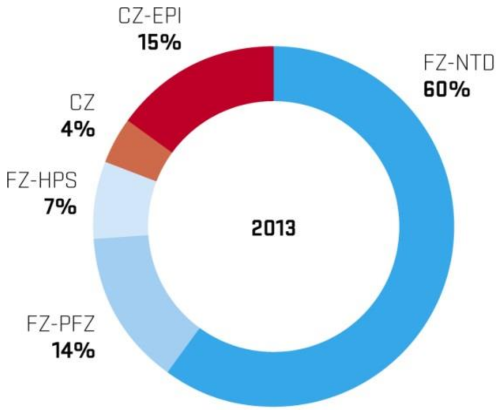
TOPSIL

APPLICATIONS, PRODUCT CAPABILITIES

PRODUCT RANGE

Main products for power devices

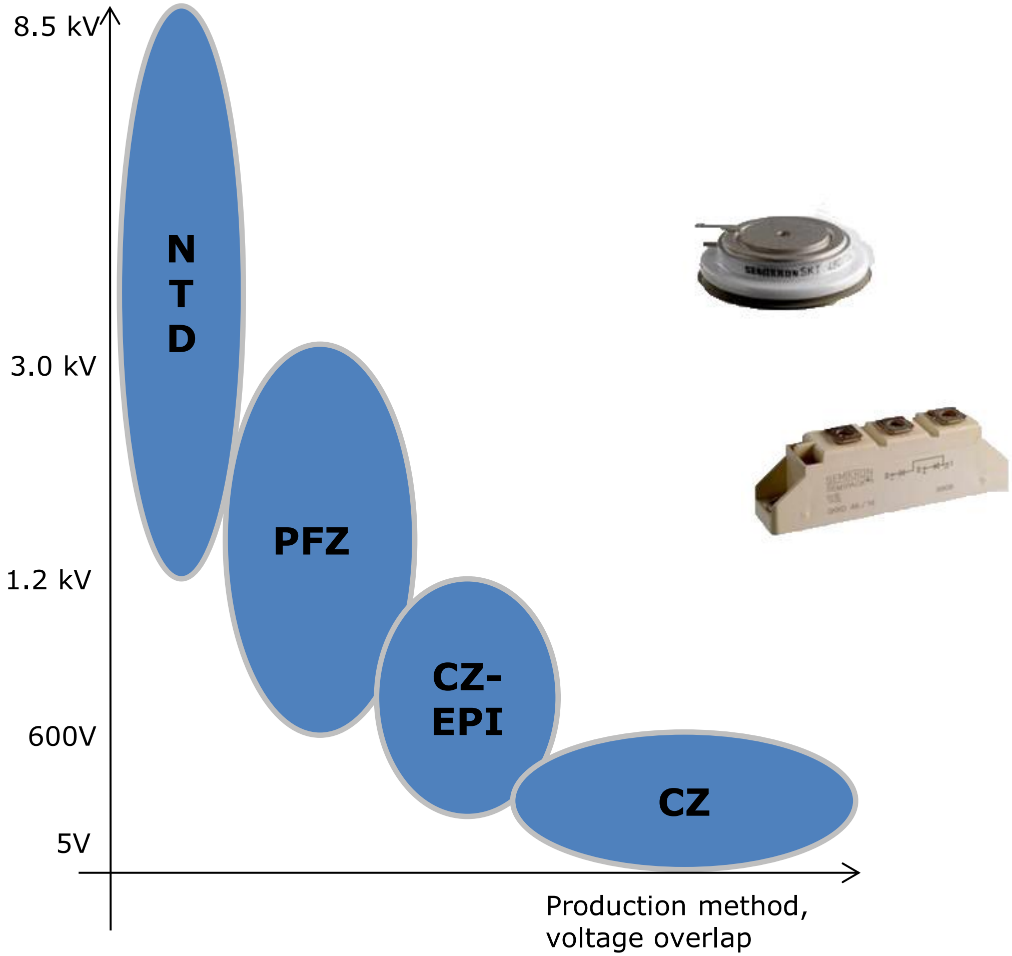
NTD: Neutron Transmutation Doped float zone silicon for high power devices
PFZ: Preferred float zone silicon for power applications
CZ EPI: EPI coated Czochralski silicon for medium and low power devises



Specialty products:

HPS	High Resistivity silicon for detector applications
UHPS	Uniform High Purity silicon for silicon drift detectors
HiRes®	High Resistivity silicon for communication devises
HiTran®	High Transparency silicon for infra red applications
PV-FZ®	Photo Voltaic Float Zone for high efficiency solar cells
GaN	Silicon wafers for GaN thin film growth

PRODUCTS, APPLICATIONS




Courtesy of Toyota hybrid

BASIC PRODUCT CAPABILITIES ≤ 150 MM.

	Float Zone	**Czochralski**
Diameter (mm):	76.2 - 153	76.2 - 153
Orientation:	<1-1-1> or <1-0-0>	<1-1-1> , <1-0-0> <1-1-0>
Doping:	n-type (Phosphorous) p-type (Boron)	n-type (Phosphorous) p-type (Boron) Arsenic, Antimony
Oxygen (atm. -3):	2.0×10^{16}	1.0×10^{18}
Resistivity (ohmcm):	**HPS 3,500 → 30,000** **NTD 20 → 4,000** PFZ 1 → 300 PV-FZ 0.5 → 10	Epi 0.2 → 70 (Si:As substrate) Epi 0.1 → 80 (Si:B substrate) **Higher epi res. on request** Cz 0.001 → 60 resistivities
Wafer:	Etched Single side polished Double side polished	Single side polished Double side polished **EPI Wafer**

FZ 200 MM. PRODUCT CAPABILITIES
PRODUCT KEY PARAMETERS

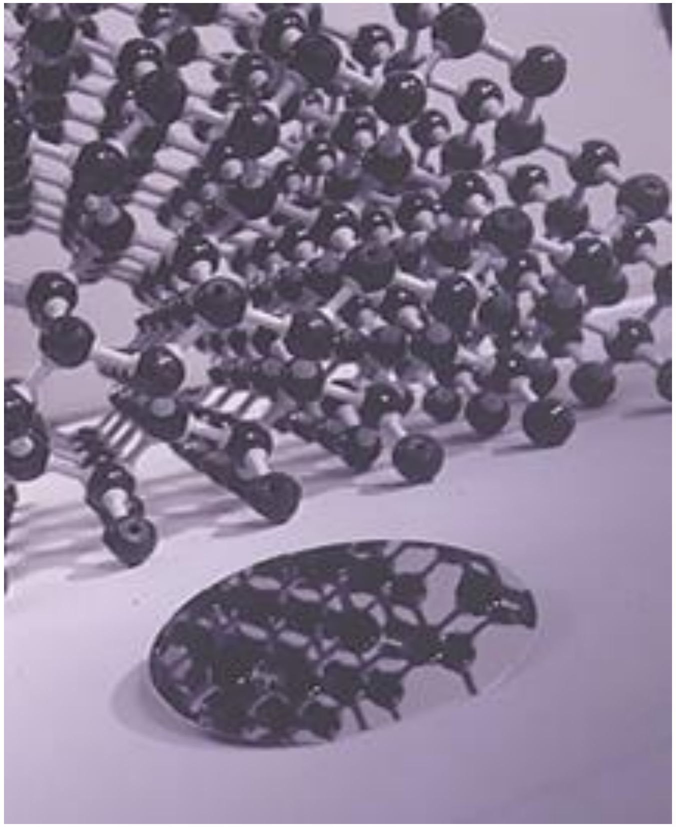
	NTD	PFZ	High resistivity material: HiRES®/HPS
Orientation:	<1-0-0>	<1-0-0>	<1-0-0>
Doping:	n-type (Phosphorous)	n-type (Phosphorous) p-type (Boron)	n-type (Phosphorous) p-type (Boron)
Oxygen atoms/cm³	$< 2.0 \times 10^{16}$	$< 2.0 \times 10^{16}$	$< 2.0 \times 10^{16}$
Metals E10 atoms/cm²	< 2	< 2	< 2
Resistivity (ohmcm):	20 – 800	20 – 100	3.500 – 30.000
Resistivity Tolerance %	< 7%	< 10%	< 50% *
RRV%	< 7%	< 14%	< 60% *

* Tolerances depending on resistivity target, test pattern and type

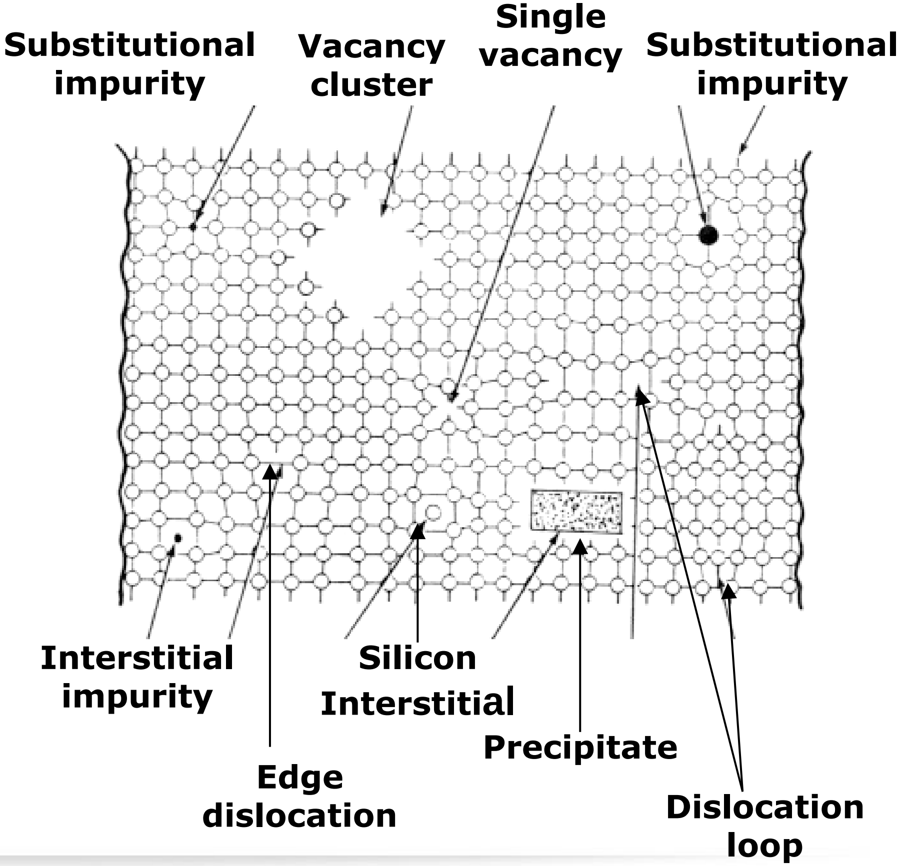
Effect of nitrogen on the properties of Si single crystals

As-grown defects in Si single crystal

Perfect crystal



Non-perfect crystal

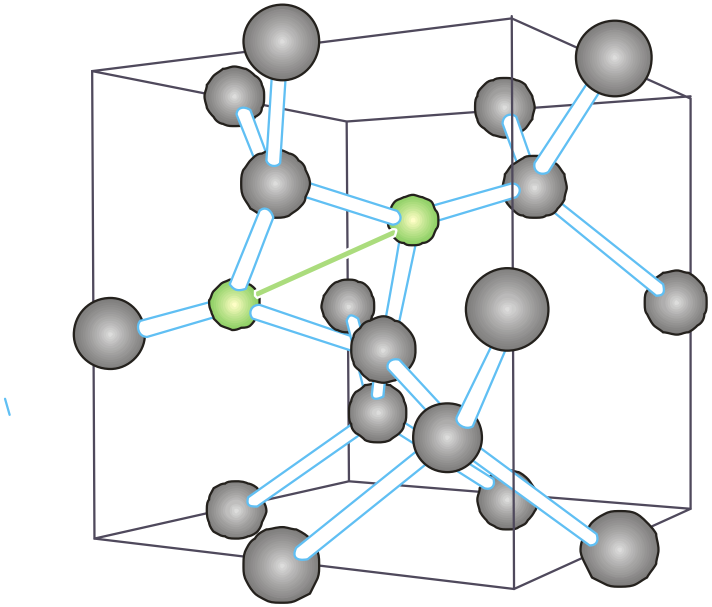


Nitrogen impact on microdefects

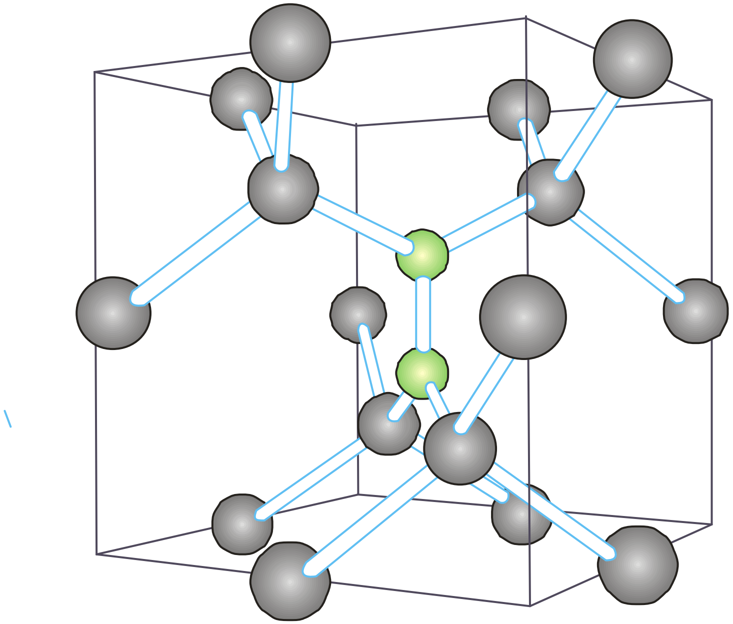
- V. Voronkov *et al.* Solid State Phenomena Vols. 131-133 (2008) pp 219-224

- Doping of silicon crystals with nitrogen has an effect on the properties of grown-in microdefects
- In Si crystals vacancies are agglomerated into voids (the voids are revealed by chemical etching as flow pattern effects)
- The void nucleation in FZ crystals occurs at temperature around 1000 ^{o}C
- The voids density is at 10^5 – 10^7 cm $^{-3}$
- The void may include 10^3 - 10^5 vacancies

Nitrogen atoms in Si lattice



N_iN_i dimer
two split-interstitials

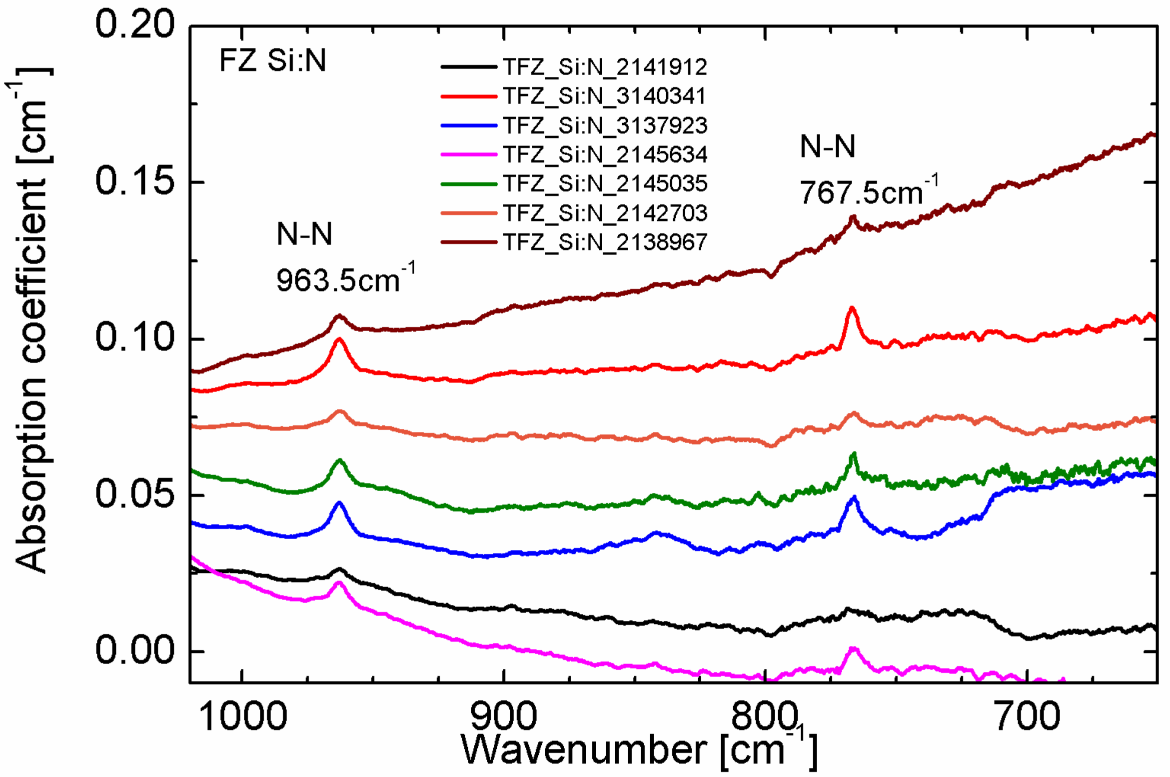


N_iN_s pair
N_s + split-interstitial

- R. Jones *et all*. Solid State Phenomena 93, (2004) 95-96

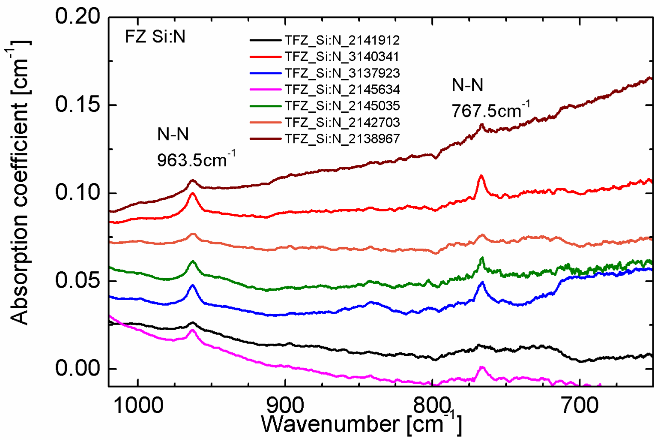
Nitrogen atoms in Si lattice

FTIR Spectra of nitrogen dimer in Si



Courtesy of Barbara Surma ITME

Nitrogen atoms in Si lattice



Courtesy of Barbara Surma
ITME

The nitrogen concentration is determined from the height of the absorption peak at 963 cm^{-1} using the following calibration formula

[nitrogen concentration [at/cm^{-3}]] = 1.83 +/- 0.24) x 10^{17} x (absorption coefficient)

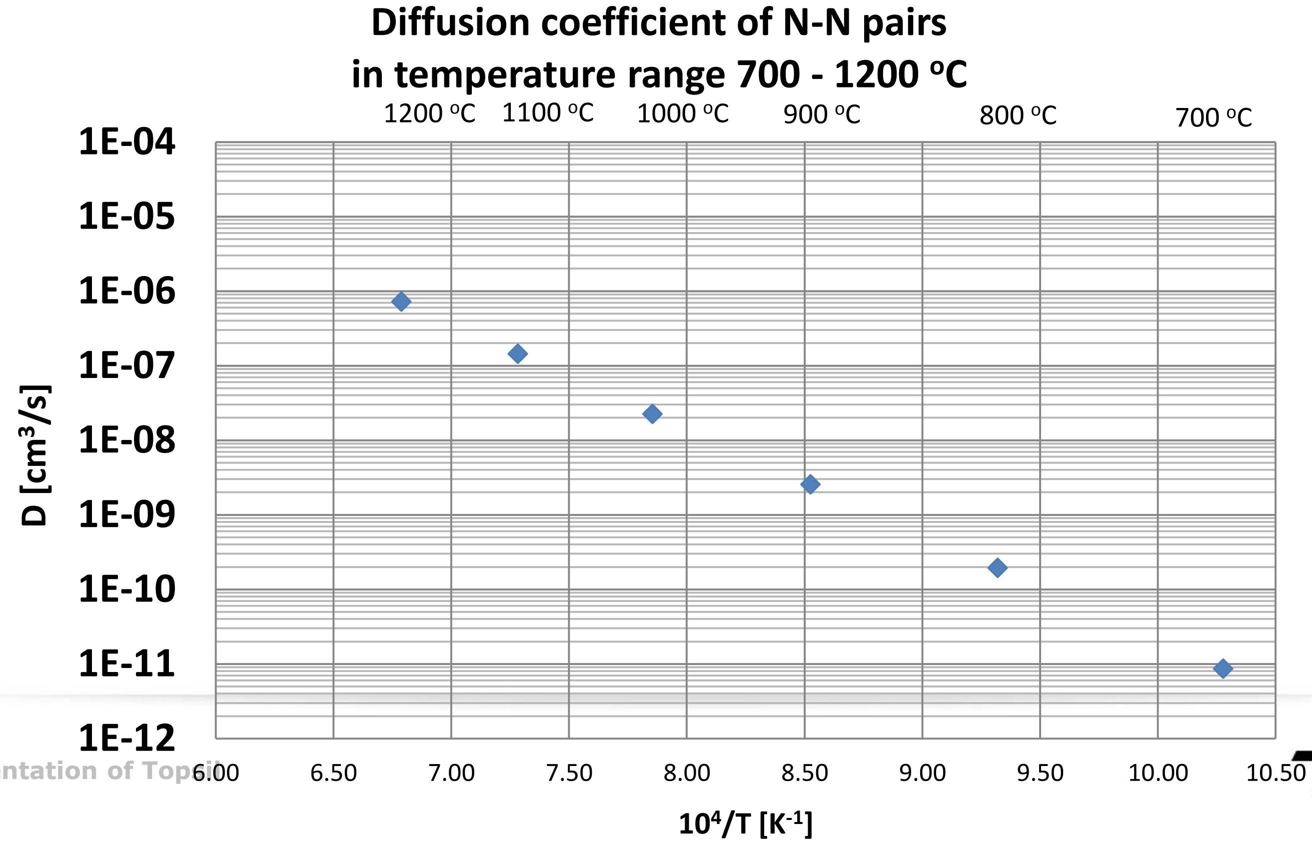
- Itoh Y *et al.* Appl. Phys. Lett. **47** (1995) 488-489

Nitrogen atoms in Si lattice

- T. Itoh and T. Abe Appl. Phys. Lett **53** (1988) p39-41

Diffusion coefficient of nitrogen N-N pairs is given by

$$D=2.7\times10^{3}\ \exp(-2.8\ \mathrm{eV}/kT)\ \mathrm{cm^3/s}$$



Nitrogen atoms in Si lattice

- W. von Ammon *et al.* Journal of Crystal Growth 226 (2001) 19–30

- N-N pairs are stable up to 1270 °C
- Interaction of N-N pairs rather than single nitrogen atoms with vacancies leads to suppression of vacancy aggregation

The following reactions are proposed to be responsible for vacancy annihilation:

- (1) $I+V \rightleftarrows 0$
- (2) $2N_i \rightleftarrows N_2$
- (3) $N_s+N_i \rightleftarrows N_2V$

- (4) $N_2+V \rightleftarrows N_2V$
- (5) $N_2V+I \rightleftarrows N_2$

- **NitroSil project scope**

NitroSil

Topsil and Polish Institute of Electronic Materials Technology (ITME) have teamed up in a scientific project scoped to gain additional insight into nitrogen behavior in float zone silicon. Under the name of NitroSil, the project is to further investigate nitrogen doping float zone technology and provide a better understanding of nitrogen behavior in this type of material.

The ultimate goal for the research project is to - in the future -
be able to introduce nitrogen enriched float zone silicon for high - energy particle detectors with increased radiation hardness.

Topsil assignments

- Development of FZ Si:N technology
- Doping with nitrogen above 1E15 cm^{-3}
- Making and delivering the high-res standard FZ Si single crystals and nitrogen-enriched single crystals (FZ Si:N)
- Thin wafer technology improvement
- Making and delivering wafers with low nitrogen concentration and high nitrogen concentration for studies at ITME
- Performing temperature/resistivity stability experiments

ITME assignments with collaboration with KiT and CiS

- Determination of nitrogen, oxygen and carbon concentrations
- Proton irradiation and study of the radiation defect centers properties
- Fabrication, irradiation and studies of radiation defect centers in detector structures
- Standard FZ Si and FZ Si:N comparative studies

Summary

Summary and Conclusion

- The mechanism of nitrogen role in suppressing of microdefects formed by vacancies aggregates arising in cooling process of FZ:Si crystals has been presented. We expect that similar effect will occur in the case of irradiation induced vacancy aggregates. The latter will be verified by the studies carried out within the framework of NitroSil project.

- After finalizing the project the new Topsil’s product: nitrogen enriched high resistivity FZ silicon wafers will be introduced on the marked of semiconductor materials.

- New product is aimed at meeting the long waiting need for radiation hard particle detectors.

Acknowledgements

This work has been partially supported by the Polish Centre for Research and Development within the framework of the NitroSil project (ID: 208346) financed by the Program for Applied Research (Contract No. PBS2 / A9 / 26/2014).

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Thank you for your attention

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