High resistivity, nitrogen-enriched FZ Si wafers for particle detectors

Michał Kwestarz (PL), Jarosław Jabłoński (PL)
Theis Sveigaard (DK), Christian Hindrichsen (DK), Leif Jensen (DK),
Pawel Kamiński (ITME), Barbara Surma (ITME), Maciej Wodzyński (ITME)

- (PL) Topsil Semiconductor Materials SA, 133 Wolczynska St., 01-919 Warsaw
- (DK) Topsil Semiconductor Materials A/S, Siliciumvej 1, 600 Frederikssund
- (ITME) Institute of Electronic Materials Technology, 133 Wolczynska St., 01-919 Warsaw

27th RD50 WORKSHOP, CERN GENEVA, Dec. 2-4 2015

PBS Program Badań Stosowanych NitroSil

www.nitrosil.com

ITME TOPSIL

OUTLINE

- Introduction
- Wafer specification
- Supply Chain of Si Wafer @ Topsil
- Resistivity Control
- Nitrogen Control
- Phosphorus Control
- Lifetime Control
- Wafer availability
- Summary

Introduction

- NitroSil project objectives included:

- development of Crystal growth and wafer production technology of a new product: nitrogen enriched high resistivity FZ silicon wafers

- this objective has been achieved

- features of nitrogen doped wafers compared to standard Si:FZ wafers are presented

FZ Si:N wafer parameters

Prime Material

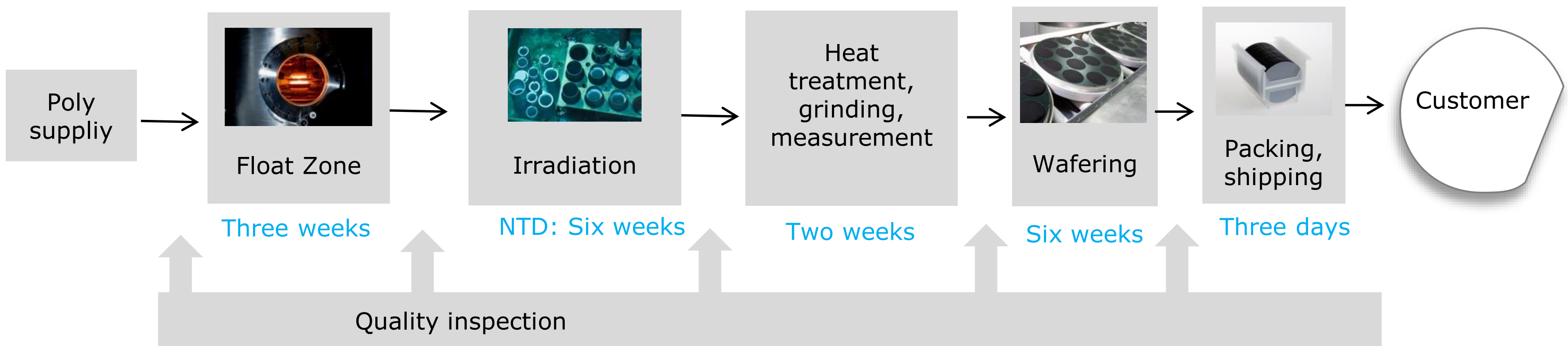
Single Side Polished

Silicon:	FZ
Diameter:	4"
Orientation:	<100>
Type:	n
Thickness:	300 +/- 15 µm
Resistivity:	2200 +/- 200 Ohm-cm
Dislocations:	free
N concentration:	1-2E15 at/cm^{-3}
O concentration:	<1E16 at/cm^{-3}
C concentration:	<5E15 at/cm^{-3}
Dopant :	Phosphorus (~2.3E12 at/cm^{-3})

Doped with phosphorus in Neutron Transmutation Process

TOPSIL SUPPLY CHAIN IN OVERVIEW

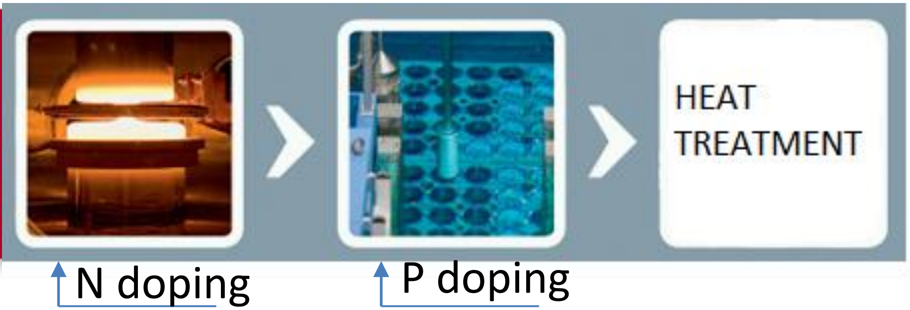
Standard process:



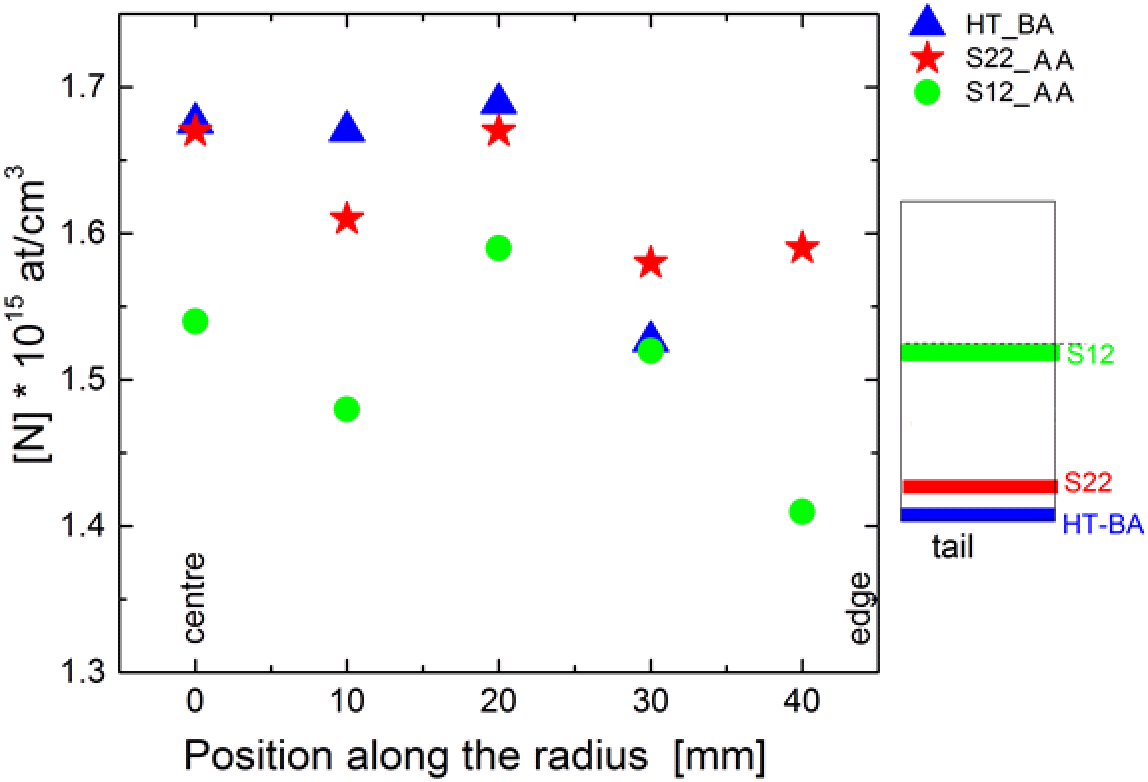
Nitrogen enriched wafers:

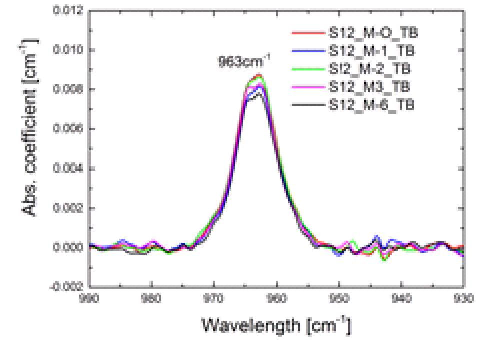
- Nitrogen doping during the crystal growth
- Phosphorus doping by Neutron Transmutation (NTD)
- Annealing to remove radiation damage
- Annealing to obtain target resistivity (decomposition of Nitrogen-Oxygen complexes)
- Key is nitrogen control on ingot level, after each step

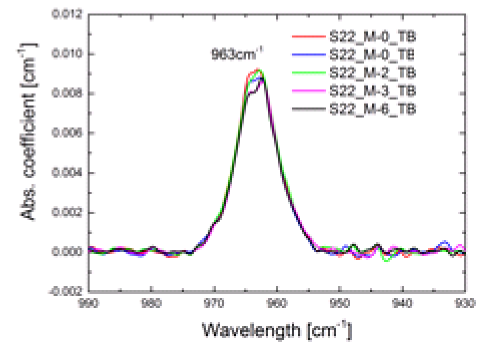
FTIR Nitrogen Concentration



Lower part of the rod, after annealing removing radiation damage







Fourier Spectrofotometer Bruker Vertex 80v

ITME TOPSIL

SIMS Nitrogen Concentration

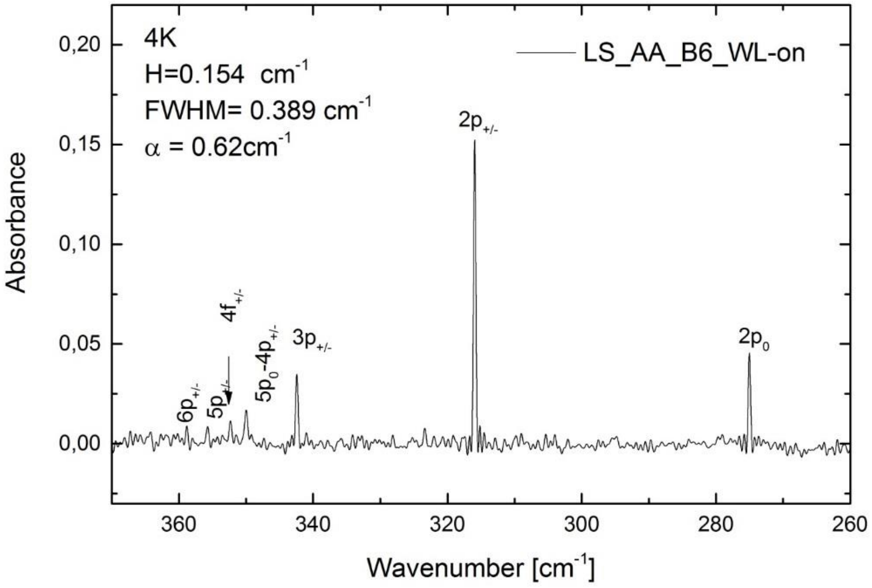
Evans Lab. (USA)
Job# C0FRF644

Average bulk nitrogen concentration

in FZ Si:N wafer: 1.4E15 cm^{-3}

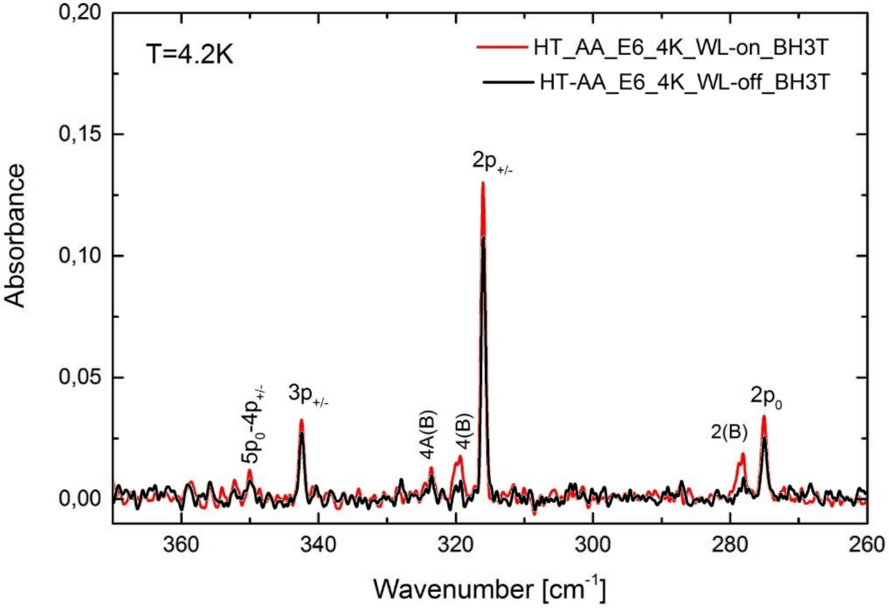
FTIR Phosphorus Concentration

Standard FZ Si



[P] 2.4E12 cm^{-3}

FZ Si:N

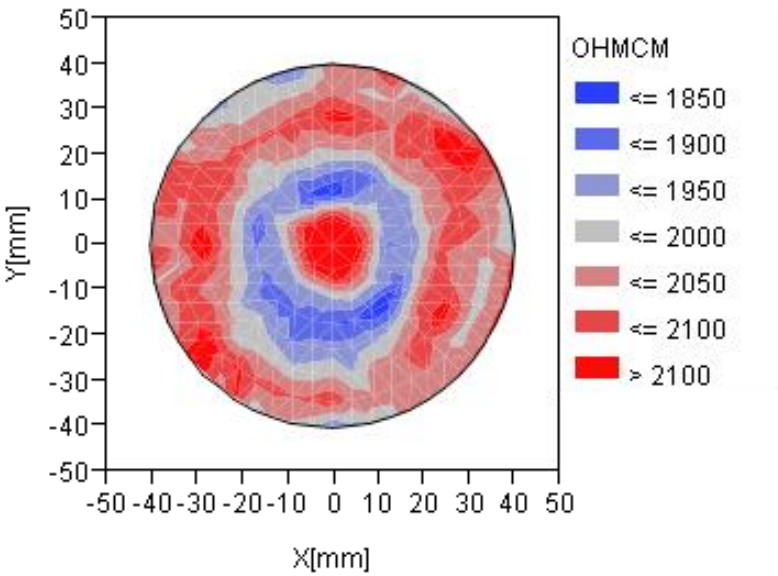


[P] 3.94E12 cm^{-3}

Resistivity control

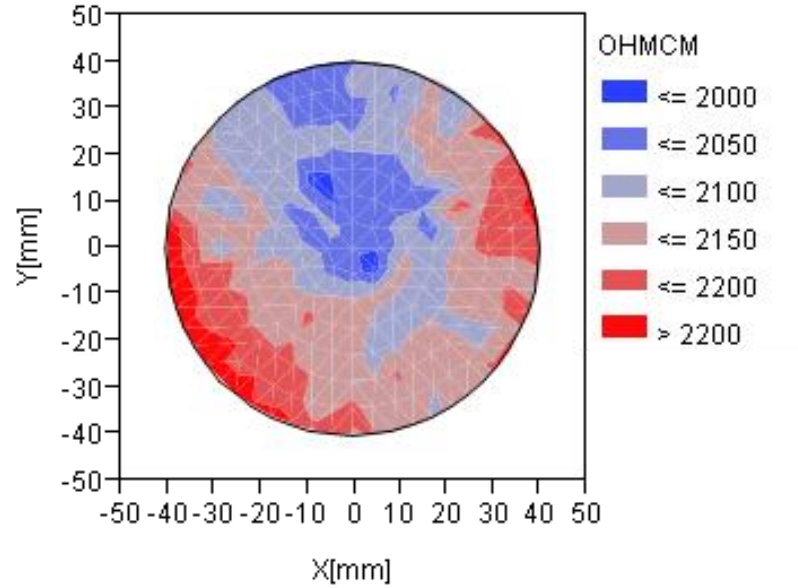
Resistivity distribution on *n*-type high-purity FZ Si wafers (T=300 K)

Standard FZ Si



Nitrogen-lean wafer
[N] < 1E14 cm^{-3}

FZ Si:N

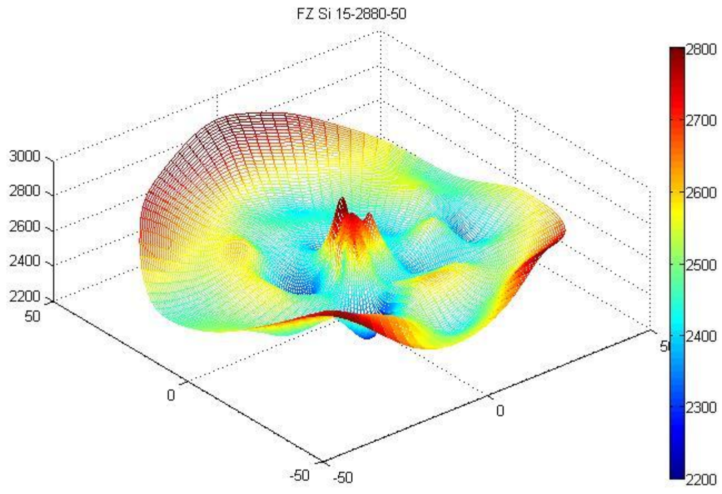


Nitrogen-enriched wafer
[N] ≈ 1.5E15 cm^{-3}

Resistivity control

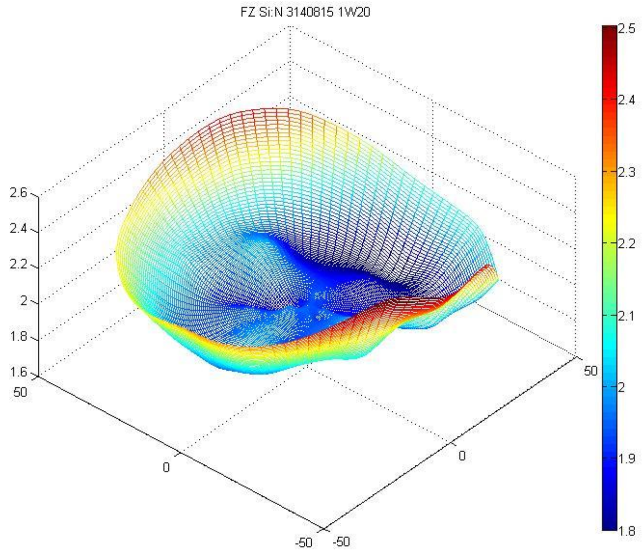
Resistivity distribution on *n*-type high-purity FZ Si wafers (T=300 K)

Standard FZ Si



Nitrogen-lean wafer
[N] < 1E14 cm^{-3}

FZ Si:N

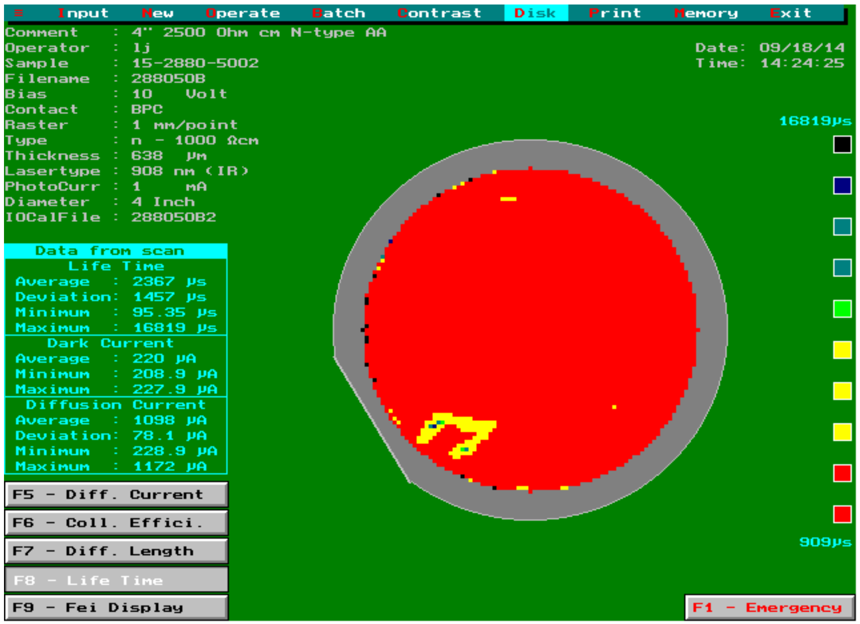


Nitrogen-enriched wafer
[N] ≈ 1.5E15 cm^{-3}

Lifetime measurements

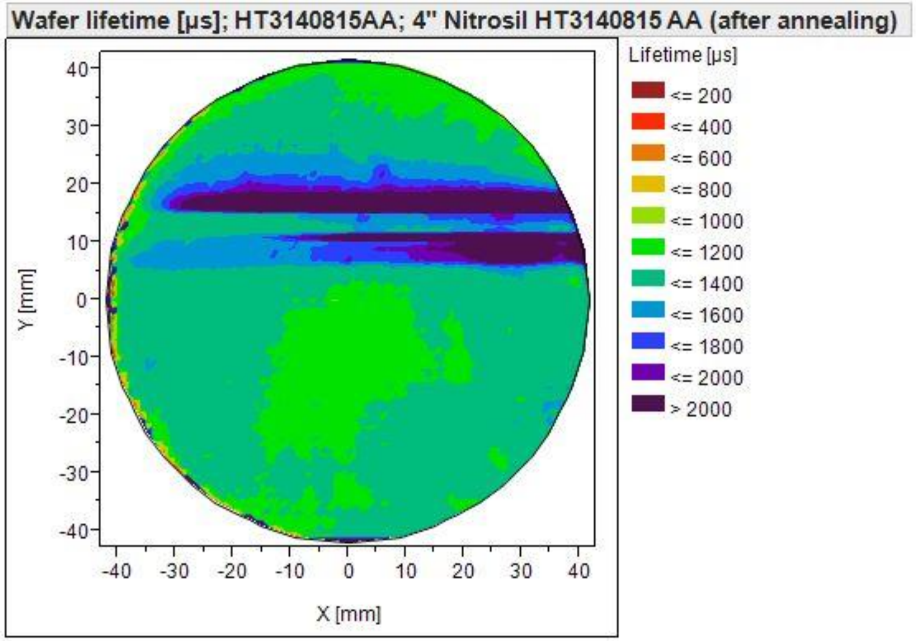
Lifetimes distribution after NTD process and annealing removing radiation damage

Standard FZ Si



T > 1000 μs

FZ Si:N



T > 1000 μs

Availability of N-enriched wafers

Availability of N-enriched wafers

- **4” wafers**
  - **2016 – wafers for testing (FOC)**
  - **Q2 2017 – commercially available**

- **6” wafers**
  - **Early stage development product available**
    (type n, orientation 100resistivity >5kOhm, nitrogen conc. >1E15 cm^-3)

Summary

Summary

- The NitroSil project milestone that is fabrication of the first high resistivity, 4”, n-type, <100>, nitrogen enriched FZ Si wafers has been achieved.

- Both the nitrogen free and the nitrogen reach wafers are characterized by a uniform resistivity distribution and a high bulk purity: [O]<1E16 cm^{-3} , [C]<5E15 cm^{-3}.

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).

www.nitrosil.com

Thank you for attention

MICHAEL KWESTARZ
NitroSil Project Coordinator

Phone: +48 22 835 19 39
Fax: +48 22 865 77 35
E-mail: mk@topsil.com
www.nitrosil.com

Topsil Semiconductor Materials SA
133 Wolczynska
01 – 919 Warsaw, Poland

Topsil Semiconductor Materials A/S
Siliciumvej 1
DK-3600 Frederikssund, Denmark

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

- 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) $N_s+N_i \rightleftarrows N_2V$

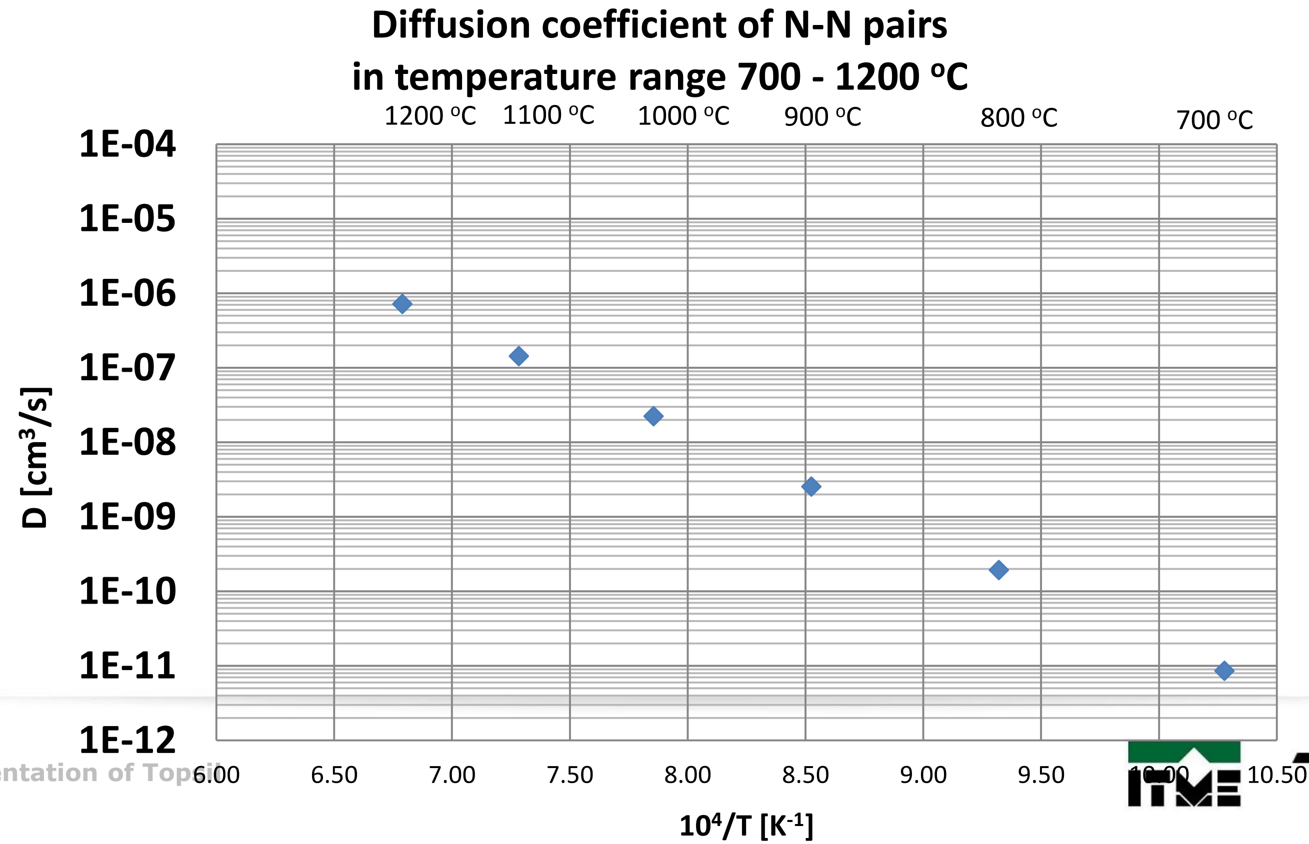
- (4) $N_2+V \rightleftarrows N_2V$
- (5) $N_2V+I \rightleftarrows N_2$

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

$$D=2.7\times10^{3}\exp(-2.8\ eV/kT)\ cm^{2}/s$$



DISCLAIMER

This document has been prepared by Topsil Semiconductor Materials A/S. Unless stated in this document the following shall apply to the information.

The information, in particular the figures, data and schedules, are preliminary and for discussion purposes only. We do not represent that such information is true, accurate or complete and it should not be relied upon as such. No independent verification exercise has been undertaken in respect of the information.

All information, opinions and estimates in this document are Topsil Semiconductor Materials A/S judgment as at the date of this document and are subject to change without notice. While this information has been prepared in good faith, no representation or warranty, expressed or implied, is made.

The information in this document is supplied on the condition that Topsil Semiconductor Materials A/S, and any related party or employee of Topsil Semiconductor Materials A/S, are not liable for any error or inaccuracy, whether negligently caused or otherwise, or for any loss or damage suffered by any person due to such an error, omission or inaccuracy as a result of such supply.