Nitrogen-doped silicon as a potentially radiation-hard material

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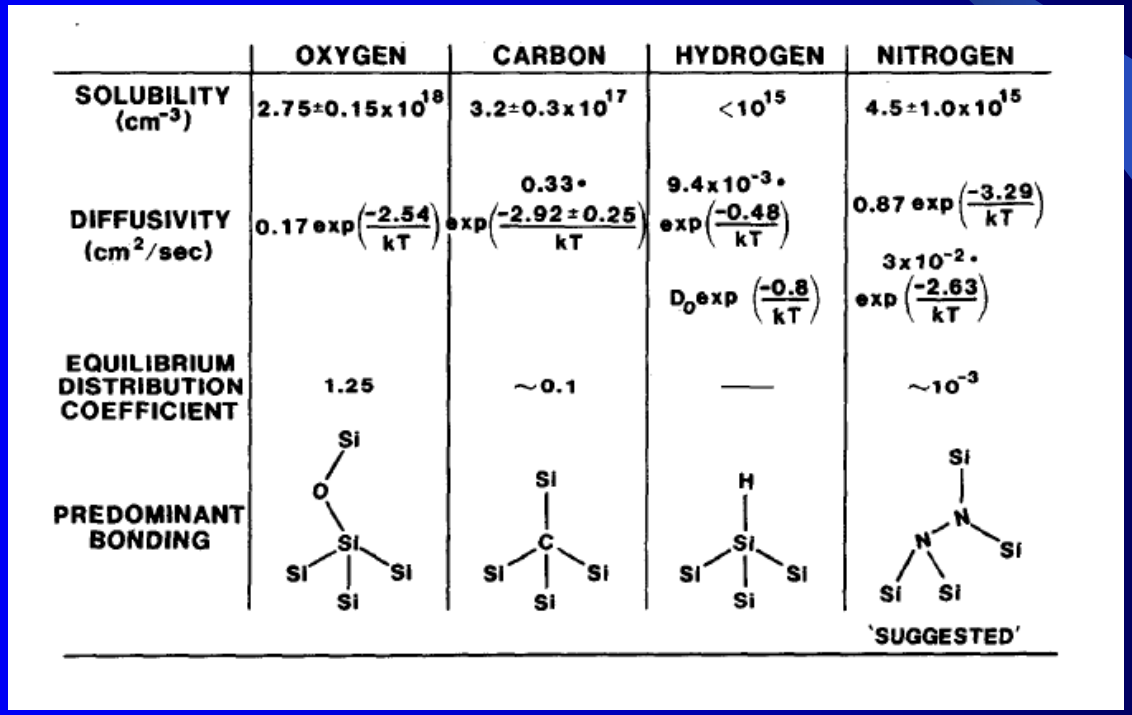
Nitrogen Influence on Properties of Silicon Single Crystals

- Enhancement of oxygen precipitation
- Improvement of gate oxide integrity (GOI)
- Increase in mechanical strength
- In FZ-Si significant reduction of *A* (*swirl)* and *D* (*flow pattern*) defects attributed to aggregates of self-interstitials and vacancies, respectively.

Comparison of Impurities Properties in Si

Covalent Radius [Å]

Si	O	C	H	N
1.11	0.73	0.77	0.32	0.75



Herman J. Stein, Mat. Res. Soc. Symp. Proc. Vol. S9. 1986 Materials Research Society

Interaction with intrinsic defects

- Recombination between interstitials and vacancies

$$N_2\,(\text{interstitial}) + V \longrightarrow N_2\,(\text{substitutional})$$

and

$$N_2\,(\text{substitutional}) + I \longrightarrow Si + N_2\,(\text{interstitial})$$

W. v. Ammon et. *al.*, Mater. Sci. Eng. B 36 (1996) 33

L. Shaik et *al.*, J. Appl. Phys. 87 (2000) 2282

Interaction with intrinsic defects

- Formation of complexes

N_2 pair and one Si vacancy: $N_2 + V \longleftrightarrow \{N_2\text{-}V\}$; 0.82 eV ↓

N_2 pair and Si divacancy: $N_2 + V_2 \longleftrightarrow \{N_2\text{-}V_2\}$; 3.61 eV ↓

Another formation path: $\{N_2\text{-}V\} + V \longleftrightarrow \{N_2\text{-}V_2\}$; 4.07 eV↓

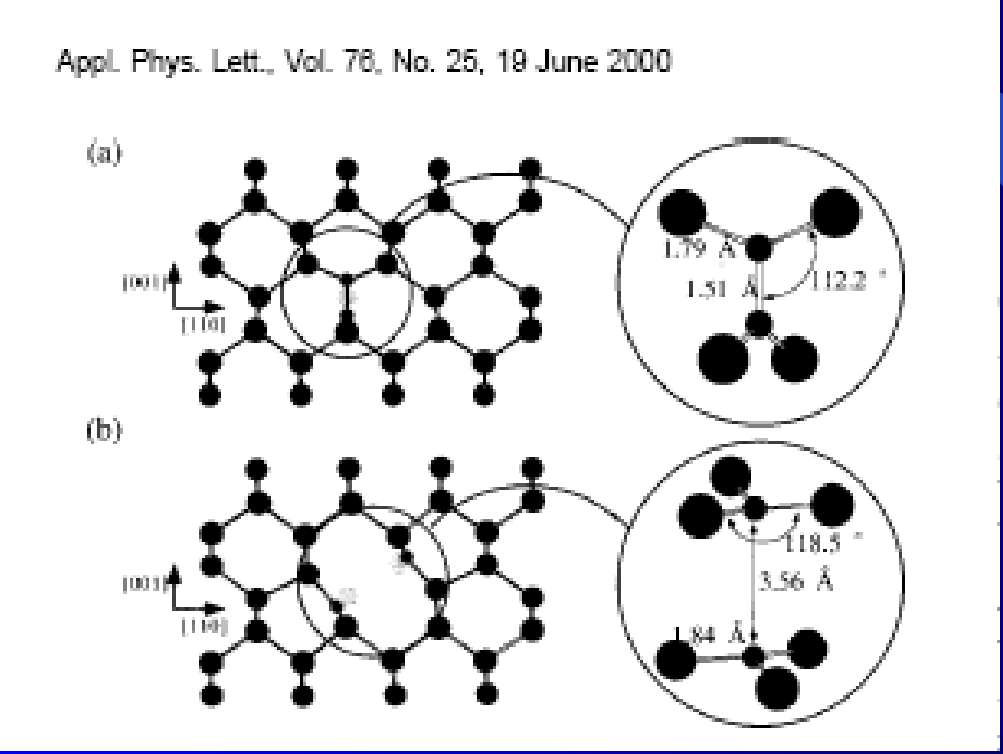
Further coupling with V: $\{N_2\text{-}V_2\} + V \longleftrightarrow \{N_2\text{-}V_3\}$; 0.30 eV↓

Models based on first principles calculations using DFT

H. Kageshima et *al*., Appl. Phys. Lett. 76 (2000) 3718

Atomic configurations of $\{N_2\text{-}V\}$ and $\{N_2\text{-}V_2\}$ complexes

Kageshima *et al.*



Interaction with impurities

- Nitrogen-oxygen (N-O) complexes in Cz Si

  They are observed through the absorption lines at 240, 242 and 249 cm^{-1} in FTIR spectra.

  They are formed in as-grown material and after annealing at 650 ^{o}C. Their concentration is by two orders of magnitude lower than that of [N].

  They disappear after annealing at 900 ^{o}C.

  Their formation may suppress the reaction of carbon with oxygen atoms.

D. Yang et *al*., Appl. Phys. Lett. 68 (1996) 487 – experimental studies

C. P. Ewels et *al*.,Phys. Rev. Lett. 77 (1996) 865 – calculations based on local density functional theory (DFT)

Interaction with impurities

- Larger complexes composed of nitrogen and oxygen atoms in Cz-Si

  N_1 - O_m (m>1) formed by attaching more oxygen atoms to N; act as a shallow thermal donor.

  N_2O_m involving pair of nitrogen atoms and oxygen aggregate; can become the nuclei of small oxygen precipitates.

  $\{N_2\text{-}V_2\}\text{-}O_m$ formed at high temperatures; also can act as the nuclei of oxygen precipitates.

X. Yu et *al.*, J. Appl. Phys. 92 (2002) 188

V.V. Voronkov et *al.*, J. Crystal Growth 273 (2005) 412

Summary

- So far the interaction of nitrogen with point defects produced by hadron irradiation has not been studied.
- The results for as-grown and nitrogen-implanted silicon suggest that nitrogen atoms may act as centers of annihilation of radiation induced native point defects, as well as traps combining aggregates of vacancies.
- The problem of silicon radiation hardness improvement due to nitrogen-doping could be studied within the framework of RD 50 project using the material offered by TOPSIL.

CEMAT
A TOPSIL COMPANY

Attn:
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QUOTATION NO. MK/445

Part: Si:N
Specification:

Page: 1
Date: 04. November 2011

Nitrogen FZ Silicon Wafers

Details of specification

Material		:	FZ Wafer
Orientation		:	Any
Type/Dopant		:	N/Ph
Resistivity	Ω cm	:	>1000
Diameter	mm	:	15 +/- 0,5
Thickness	µm	:	2000 +/- 100
Finish		:	Polished
Edge rounding		:	Polished

			Detector limit 0.5*1E16		10*IE14
	Resistivity		Carbon	Oxygen	Nitrogen
Ingot no.	Ohm cm	type	1E16	1E16	1E14
3137923	2000	N	0,10	1,10	15,00
2138967	4500	N	0,00	0,00	9,00
2141912	4000	N	0,10	0,60	9,00
2142595	5000	N	0,00	0,20	10,00
2142703	6500	N	0,00	0,20	12,00
2143317	5000	N	0,20	0,10	13,00
2144748	5000	N	0,00	0,30	11,00
2145035	5000	N	0,00	0,50	14,10
2145634	4000	N	0,00	0,70	14,00
3140341	2000	N	0,30	0,90	13,00

Price/Wafer : EUR 116,25

Delivery time : Approx. 1 week from receipt of order

Terms of payment : Net 30 days
Terms of delivery : FCA Warsaw, Incoterms 2000

Validity of quotation: 30 days

Delivery of ± 10% on the ordered quantity and ± 25% on the smaller orders (≤ 1,000 Pcs./ ≤ 1,000 mm) is considered standard.

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QUOTATION NO. MK/446

Part:
Specification: Si:N

Page: 1
Date: 04. November 2011

Nitrogen doped FZ Silicon Wafers

Details of specification

Material		:	HiRes
Orientation		:	(1-0-0) +/-0,5 Deg
Type/Dopant		:	N/Ph
Resistivity	Ω cm	:	>5000
Lifetime	µsec.	:	≥1000
Carbon	Atoms/Cm³	:	< 2.0x1E16
Oxygen	Atoms/Cm³	:	< 2.0x1E16
Diameter	mm	:	150 +/- 0,2
Flat, Primary	mm	:	SEMI standard
Flat, Secondary	mm	:	None
Thickness	µm	:	675 +/- 10
Finish		:	Single side polished
Edge rounding		:	Yes, standard
TTV	µm	:	≤5
Bow	µm	:	≤30

Quantity : Minimum 25 pcs (75 pcs available in stock).
Price/Wafer : EUR 116,25

Delivery time : Approx. 1 week from receipt of order

Terms of payment : Net 30 days
Terms of delivery : FCA Warsaw, Incoterms 2000

Validity of quotation: 30 days, and only as long as said item remains available in stock

Delivery of ± 10% on the ordered quantity and ± 25% on the smaller orders (≤ 1,000 Pcs./ ≤ 1,000 mm) is considered standard.

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Acknowledgements

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