

High sensitivity infrared absorption spectroscopy and infrared defect dynamics of silicon crystal

(19) Nitrogen complexes, past, present and future

シリコン結晶の高感度赤外吸収と赤外欠陥動力学(19)窒素複合体の過去現在未来

Osaka Pref. Univ.¹, °N. Inoue¹, S. Kawamata¹ and S. Okuda¹大阪府大研究推進¹, °井上直久¹, 川又修一¹, 奥田修一¹E-mail: inouen@riast.osakafu-u.ac.jp**Past and present**

It was revealed by IR that nitrogen makes various complexes with vacancy (V), interstitial (I), C and O, in contrast to O and C. Detection and assignment was difficult due to low concentration for experiment and to complicated configuration for theoretical work. Parallel study of experiment and theory [1] made fruitful results. Sometimes inadequate assignment happened as marked by the broken underline below. Improvement of sensitivity of experiment from 10^{14} to below $10^{13}/\text{cm}^3$ [2] and accuracy of wavenumber calculation from 80 cm^{-1} [3] to less than 1% [4], combined with each other, solved problems as summarized in the table (*: final assignment). The absorption from other complexes was excluded by preparing the IR database. Complexes with the point defects are enriched by the electron irradiation [5].

Complex	IR cm^{-1}	History,				*: establish
Ns	653	impl.&anneal dope/Mitchel75	<u>EPR→Ns/Brower82</u>			<u>IR/Stein85*</u>
NN	766,963	IR/Abe81	2N/Stein85			<u>4atom ring/Jones94*</u>
NNO	801,996,1027	IR/Wagner88	<u>4atom ring/Jones94*</u>	anneal NN←→NNO /Qi91		
NNO2	810,1018	IR/Wagner88	suggest/Jones94	<u>deny/EwelsT96</u>		<u>calc/Inoue02*</u>
Ni	551	suggest/Stein85	<u>denycalc690/Jones94</u>	calc550/Goss03	<u>irradanneal/Inoue14*</u>	
					<u>as-grown/Inoue13,16</u>	
NO	556	<u>chain&STD model/EwelsT96</u>		annealNi←→NO/Inoue19		
VNs	688	(687/350oC/Stein85)	calc/Goss03	Irrad&anneal/Inoue18*	<u>as-grown/Inoue(13)19</u>	
VNN	726,778	<u>model/Kageshima00</u>	calc/Inoue02,Goss03		Irrad/Inoue14*	
VVNN	689	<u>model/Kageshima00</u>	calc/Inoue02		irradanneal 400°C /Inoue14*	
INN?	930, 953	calc/Goss03	irrad/Londos16			
STD	714,736,655,973,1002,1065	<u>7level/Suezawa86</u>	H-exclusion/EwelsT96		<u>N2model/Suezawa87</u>	
		N+O2-4/Voronkov02	4 atom ring&double ring/Ewels96	calc/Inoue06	7 configuration model/Inoue19	

Future Assignment of unattended absorption peaks, detection of STD and IN complexes, and analysis of behavior of V-I-O complexes in growing silicon, are left. Nitrogen is used as a dopant to SiC, in diamond donor and later VN as a quantum dot, and IR study also performed in GaAs. Research on N in Si will provide important information to them.

References [1] Harada, Inoue et al., Physica B, 308-310, 244 (2001). [2] Inoue et al., Phys. Stat. Sol. C, 9, 1931 (2012). [3] R. Jones et al., Phys. Rev. Lett., 72, 1882 (1994). [4] J. P. Goss et al., Phys. Rev. B, 67, 045206 (2003). [5] N. Inoue et al., AIP Conf. Proc., 1583, 19 (2014); J. Appl. Phys., 123, 185701 (2018).