Junction Technology Group:
Thurs, July 11, 2013
noon - 4:00 pm

SEMICON West 2013
Moscone Center (San Francisco, CA)

SPONSORS

Advanced Ion Beam Technology

Axcelis

Cameca

Centrotherm

EAG Labs

KLA-Tencor

Nissin Ion Equipment

SEN Corp.

Ultratech

Ion Implantation and Annealing: New Process and Products
Co-Chairs: John Borland & Michael Current

Michael Current of Current Scientific:
"Microwave and RTA annealing of Phos-doped, strained Si(100) and (110) implanted with molecular carbon ions"

Jeff Gelpey of Centrotherm:
"Low temperature oxidation & nitridation process enabling advanced junctions".

Jeff Hebb of UltraTech:
"Laser spike anneals for finFETs".

Gary Mount of EAG:
"Junction evaluation using Electron Beam-Induced Current (EBIC)".

Ice cream break and networking

John Borland of J.O.B. Technologies:
"High mobility Ge channel formation by selective liquid phase epitaxy (LPE) using Ge + B plasma implantation & laser melt annealing".

Yoshiki Nakashima of Nissin:
"Damage control with cluster ions and heated implantation".

Mitch Taylor representing Cameca:
"Advanced metrologies for advanced devices and materials: SIMS, LEXES, ATP".

Dick James of Chipworks:
"Leading edge Si devices: an update".

IIT14 conference: June 29-July 4, 2014:
20th international conference on ion implantation technology, annealing, applications to advanced materials & devices.

Conference venue: Hilton Hotel, Portland OR

Conference chairmen:

Aaron Vanderpool: Intel
Benjamin Columbeau: AMAT/VSEA

Abstract deadline: Feb 7, 2014 (5 days after Superbowl2014)

website: www.iit2014.net
email: della@avs.org

IIT14 school: June 26-28, 2014: 3-day intensive tutorial on ion implantation machines & process, annealing & process control metrologies. Faculty of international experts, ≈600 page textbook.

In Memorium: June 2013

James W. Mayer

"Father" of many ion beam technologies.
Threshold adjust implants, , amorphous-Si regrowth,
Rutherford Backscattering Spectroscopy,
silicide film growth & characterization, materials science
teacher to many at Caltech, Cornell, ASU.

Kenneth G. Stephens

Leader of ion beam technology center at the
University of Surrey, Guildford, UK. Teacher to many
ion implantation and ion beam physics students.
Co-chair of IIT90.

Microwave and RTA Annealing of Phos-doped, Strained Si(100) and (110) Implanted with Molecular Carbon Ions

Michael I. Current
Current Scientific, San Jose, CA USA
currentsci@aol.com

Yao-Jen Lee
National Nano Device Laboratories, Hsinchu, Taiwan

Yu-Lun Lu , Ta-Chun Cho, Tien-Sheng Chao
Dept of Electrophysics, National Chiao Tung University, Hsinchu, Taiwan

Hiroshi Onoda, Karuppanan Sekar, Nobuhiro Tokoro
Nissin Ion Equipment, Kyoto, Japan

outline:

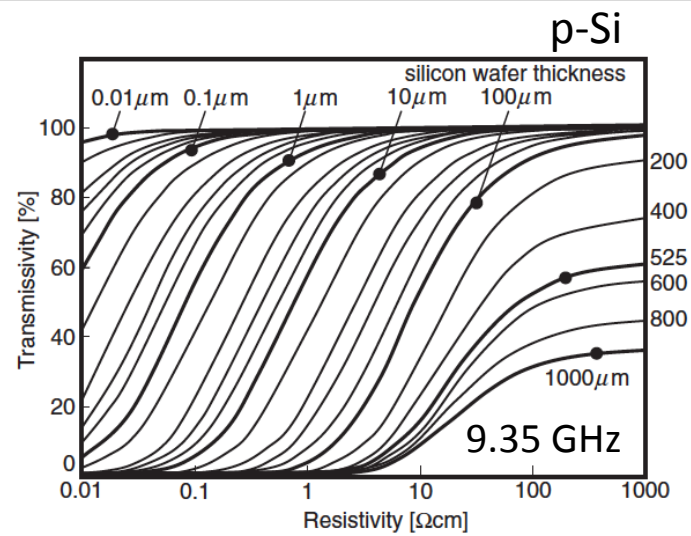
Comparison of MWA & RTA: Activation & SPE
Experimental details: Implants, MWA, RTA
Results: SIMS, TEM, R_{sheet}, XRD
Summary

What is different about MWA ?

Light	Wavelength	Frequency	Photon Energy
uv	10-400 nm	30 PHz - 750 THz	124 - 3 eV
visible	400-750 nm	750 - 400 THz	3.2 - 1.7 eV
IR	750 nm - 1 mm	400 THz - 300 GHz	1.7 eV - 1.24 meV
uW	**1 mm - 1 m**	**300 GHz - 300 MHz**	**1.24 meV - 1.24 ueV**
radio	1 -10^5 m	300 MHz - 3 Hz	1.24 ueV -12.4 feV

- u-wave light has photon energies far below E_{gap} (Si): no carrier creation.
- u-wave light is absorbed by free carriers with Ohmic heating.
- u-wave heating (phonon generation) from dipole excitations, etc.
- "coherent" excitation (non-thermal) reported in ceramics, chemicals, etc.

Jpn. J. Appl. Phys. **48** (2009) 021204 T. Sameshima et al.



Current Scientific

NARL

財團法人國家實驗研究院 國家奈米元件實驗室 National Nano Device Laboratories

國立交通大學 National Chiao Tung University

日新イオン機器株式会社 NISSIN ION EQUIPMENT CO.,LTD.

MWA Heating

Micro-wave Anneal Chamber:

- 3 to 5 magnetrons
- 5.8 GHz
- Chamber tuned to minimize static modes
- Pyrometer temperature sensor
  - (line of sight to wafer center bottom)

Wafer temperature depends on:

- Magnetron power
- Power-on time period
- Location of Si and Quartz susceptor wafers

Typical maximum wafer temperature:

- 350 to 500 C (≈300 s)
- Minimal dopant diffusion

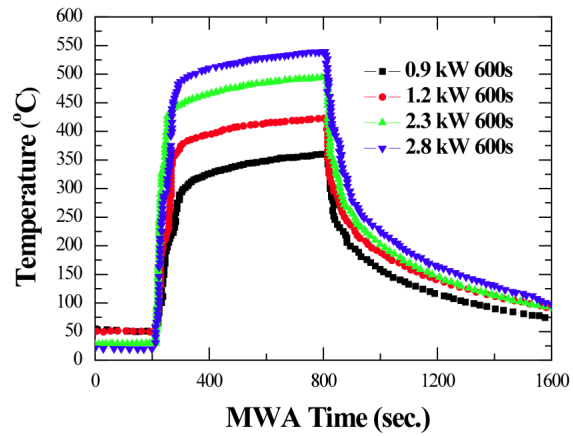


Fig. 2. Comparisons of temperature profiles versus MWA time at different MWA power. The MWA time was defined as the period when the microwave power was turned on.

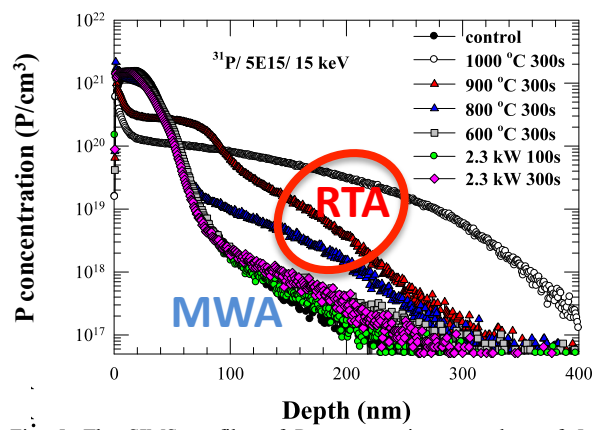


Fig. 5. The SIMS profiles of P concentration at a dose of 5×10^{15} ions/cm^2. The P distribution after the RTA over 800 ºC shows deeper dopant diffusion, while the MWA resulted in no significantly dopant diffusion.

Current Scientific

NARL

財團法人國家實驗研究院 國家奈米元件實驗室 National Nano Device Laboratories

國立交通大學 National Chiao Tung University

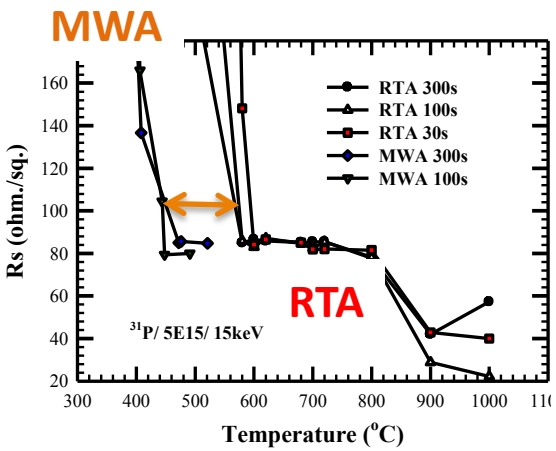
日新イオン機器株式会社 NISSIN ION EQUIPMENT CO., LTD.

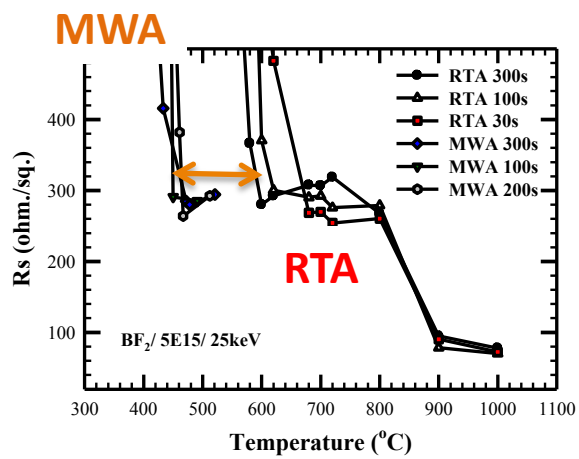
MWA vs RTA: Dopant Activation Rate

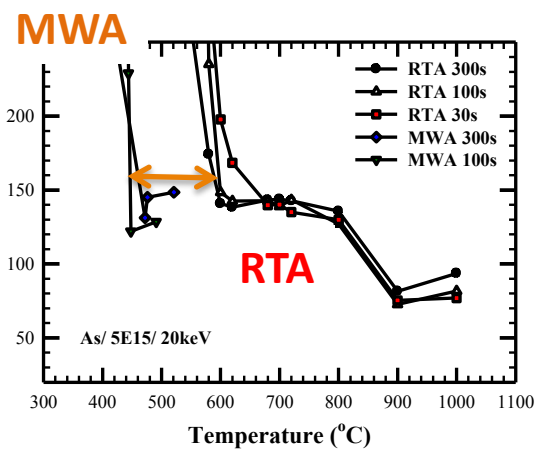
MWA activates P, As and BF_2 implants at ≈450 C.

RTA activates dopants at ≈570 C.

Implication: c-Si re-growth (SPE) occurs faster and at lower temperatures for MWA than RTA.







Y.J. Lee et al., IIT12

Current Scientific

NARL

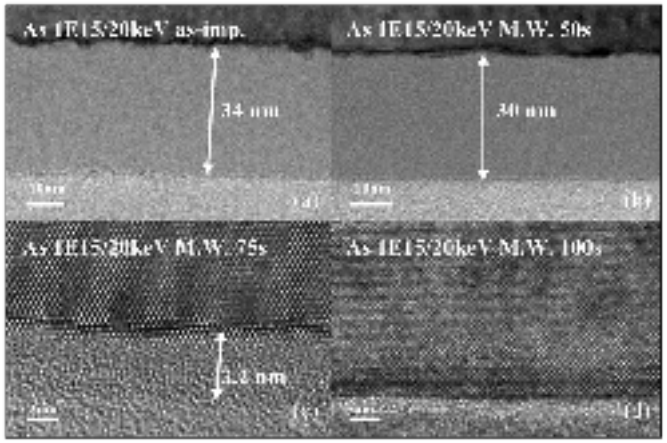
財團法人國家實驗研究院 國家奈米元件實驗室 National Nano Device Laboratories

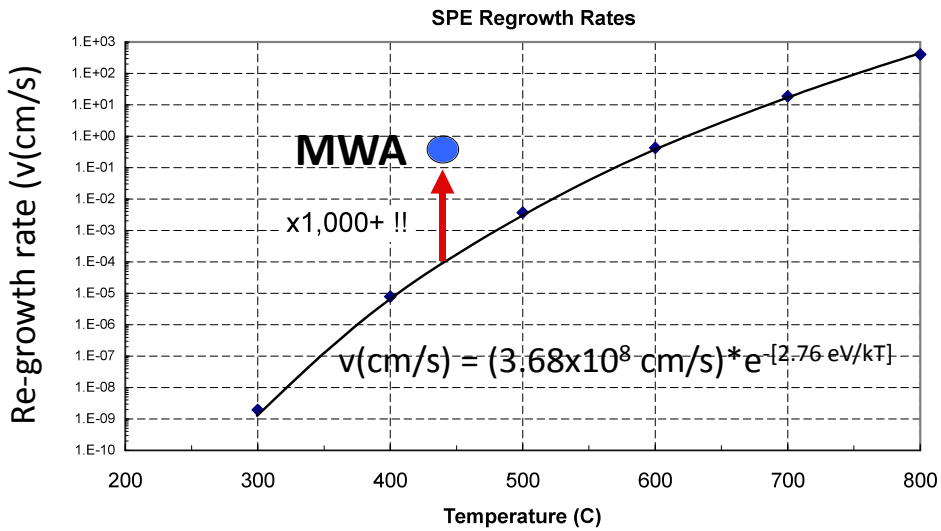
國立交通大學 National Chiao Tung University

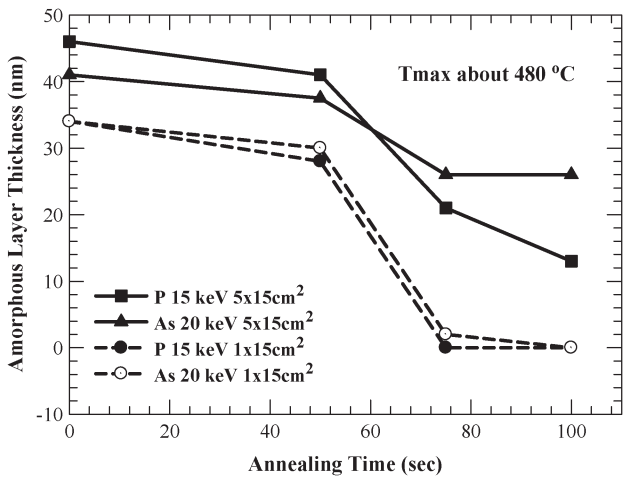
日新イオン機器株式会社 NISSIN ION EQUIPMENT CO., LTD.

MWA vs RTA: re-growth kinetics

c-Si re-growth (SPE) rates measured for P and As implants are ***≈10³ times faster*** for MWA at ≈450 C than thermal rates.







F.K. Hsueh et al., IEEE Trans Electron Dev. **58** (2011) 2088.

Current Scientific · NARL · NDL 財團法人國家實驗研究院 國家奈米元件實驗室 National Nano Device Laboratories · 國立交通大學 National Chiao Tung University · 日新イオン機器株式会社 NISSIN ION EQUIPMENT CO., LTD.

Experimental Conditions: strained nMOS

Implants: (Nissin CLARIS)

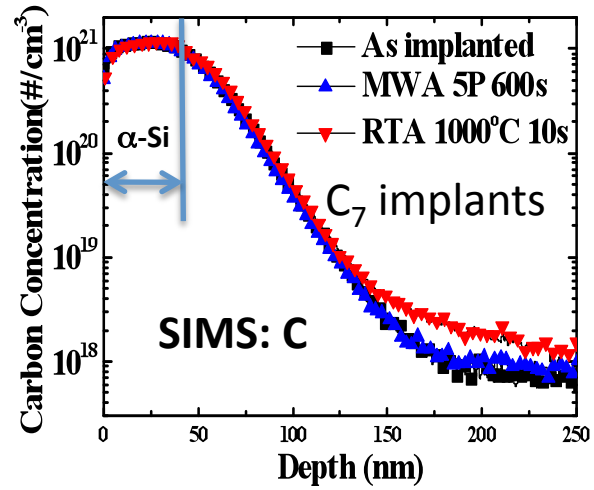
$C_7H_7^+$

10 keV / 3e15 C/cm^2,
6 keV / 8e14 C/cm^2,
2 keV / 6e14 C/cm^2

and

P^+

15 keV / 4e15 P/cm^2



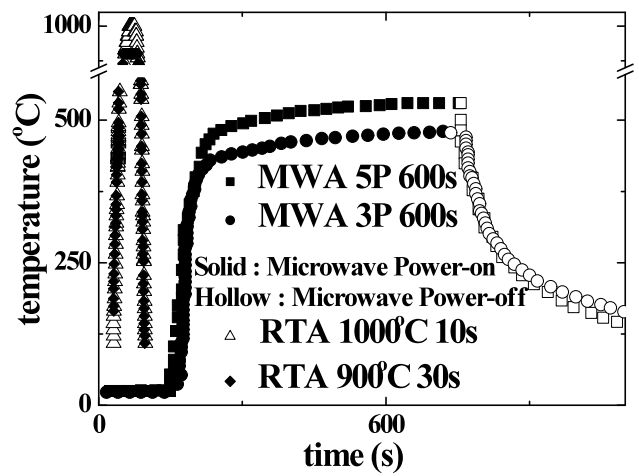
Anneals:

MWA: (DSG AXOM-300)

3 or 5 Magnetrons, 600s
30 min N_2 chamber purge

RTA: (AllWin 810)

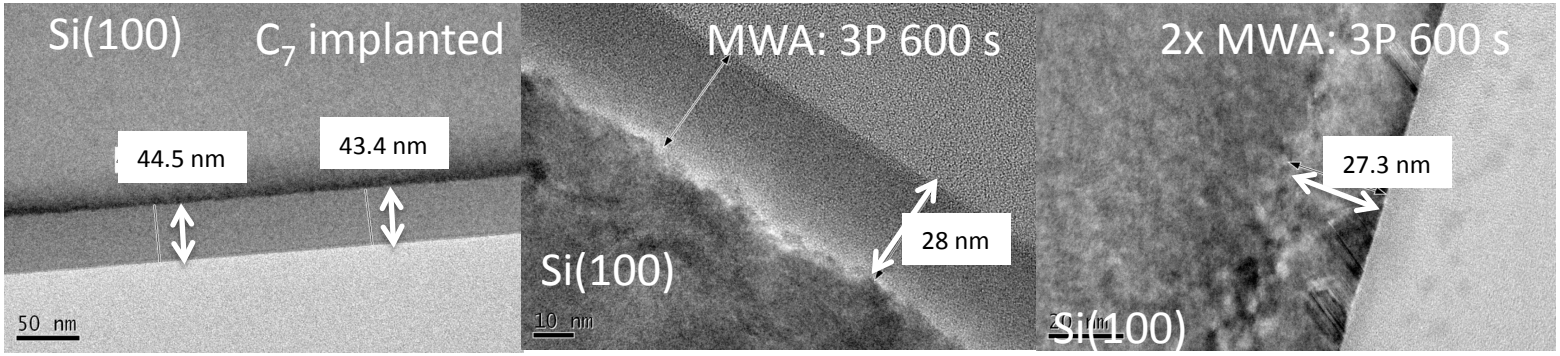
600, 750, 900 C, 30s
and 1000 C, 10s



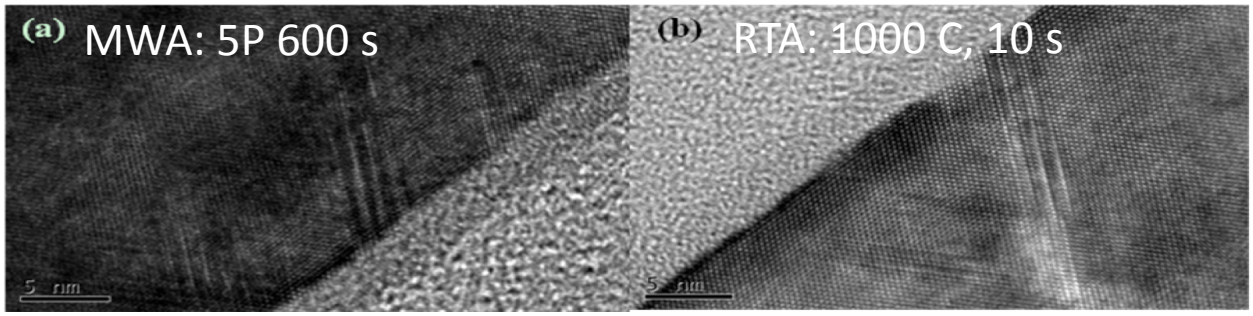
Current Scientific
NARL
財團法人國家實驗研究院 國家奈米元件實驗室 National Nano Device Laboratories
國立交通大學 National Chiao Tung University
日新イオン機器株式会社 NISSIN ION EQUIPMENT CO., LTD.

Damage Recovery: C_7H_7 Implants

MWA at 3P 600s re-grows ≈1/3 of a-Si layer. MWA at 5P 600s re-grows all a-Si.



Both MWA and RTA leave dense "twin-like" dislocations near surface (at regions of high C (10^{21} C/cm^3) concentrations).



Current Scientific

NARL

財團法人國家實驗研究院 國家奈米元件實驗室 National Nano Device Laboratories

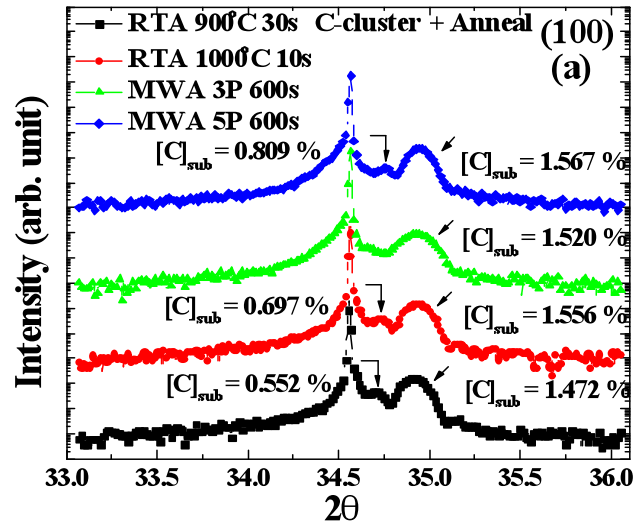
國立交通大學 National Chiao Tung University

日新イオン機器株式会社 NISSIN ION EQUIPMENT CO., LTD.

Carbon Strain: C_7H_7 implants, XRD

Si(100):

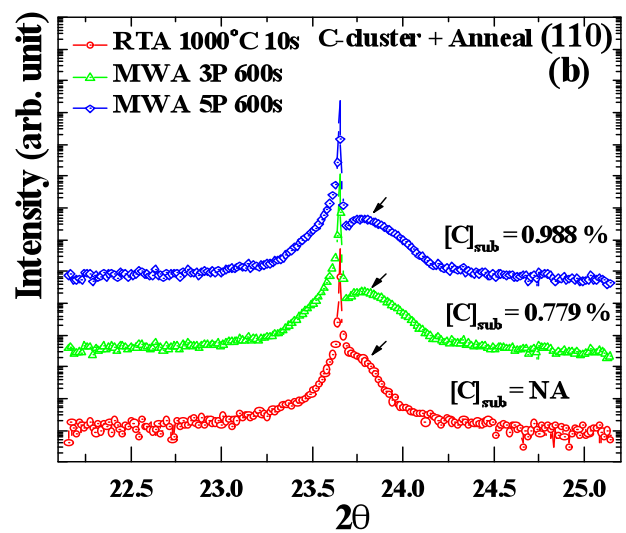
Both MWA (480 -510 C, 600 s) and RTA (900-1000 C, 10 s) result in high (≈1.5%) substitutional C content.



Si(110):

MWA (480 -510 C, 600 s) gives lower Csub (0.78-0.99%) content than Si(100).

RTA (1000 C, 10 s) results in low (<0.3%) substitutional C content.



Current Scientific

NARL

財團法人國家實驗研究院 國家奈米元件實驗室 National Nano Device Laboratories

國立交通大學 National Chiao Tung University

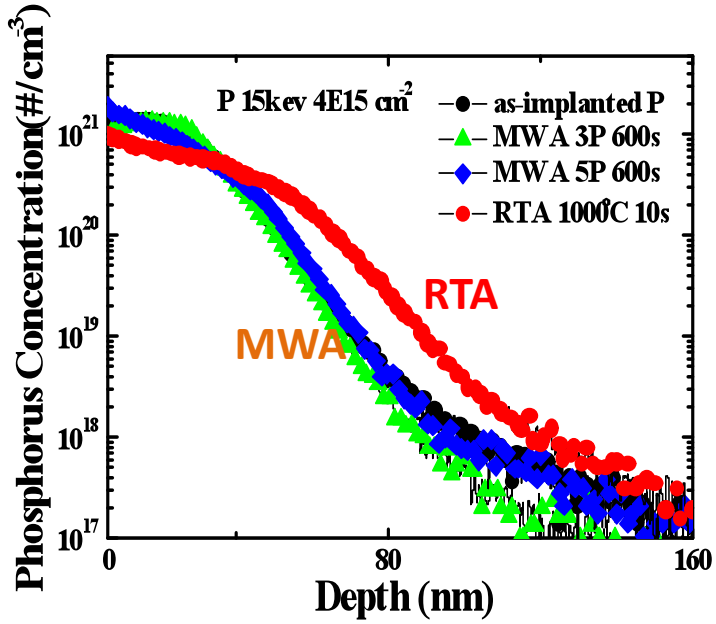
日新イオン機器株式会社 NISSIN ION EQUIPMENT CO., LTD.

C_7H_7 & P implants: SIMS, TEM

SIMS: P

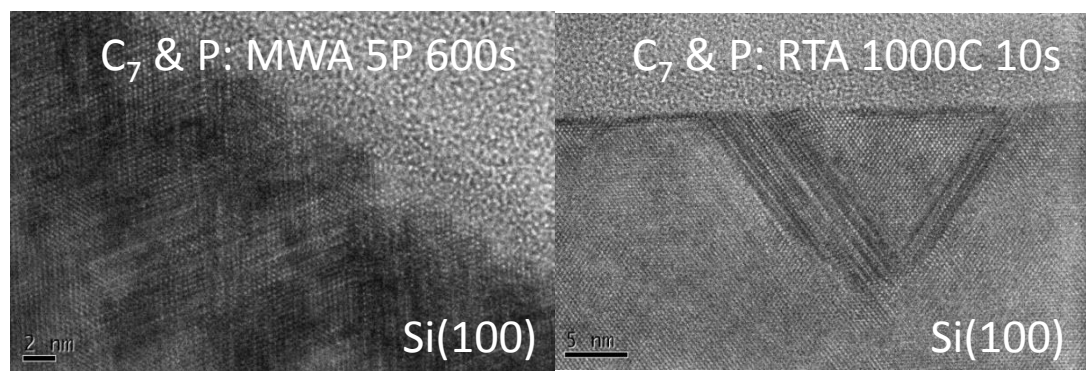
No substantial P diffusion for MWA.

Some P diffusion for RTA 1000 C 10 s.



TEM:

Dense twin-like dislocations seen near surface (high C content) in both MTA & RTA.



Current Scientific

NARL

財團法人國家實驗研究院 國家奈米元件實驗室 National Nano Device Laboratories

國立交通大學 National Chiao Tung University

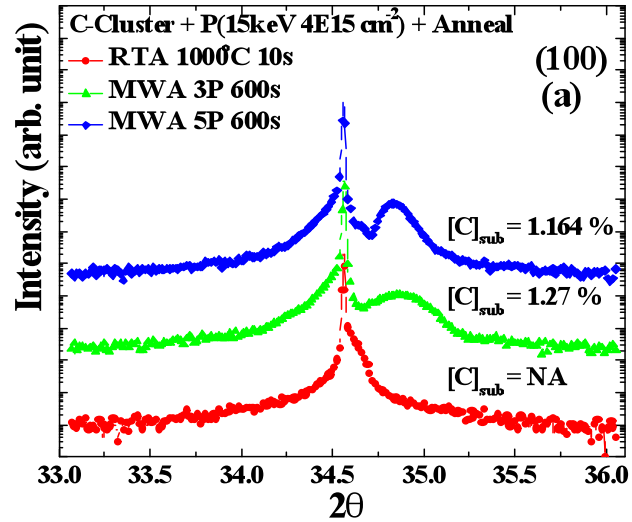
日新イオン機器株式会社 NISSIN ION EQUIPMENT CO., LTD.

Carbon Strain: C_7H_7 & P implants, XRD

Si(100):

MWA (480 -510 C, 600 s) with C_7 & P implants has lower (1.15-1.3%) C_{sub} than C_7 alone (≈1.5%).

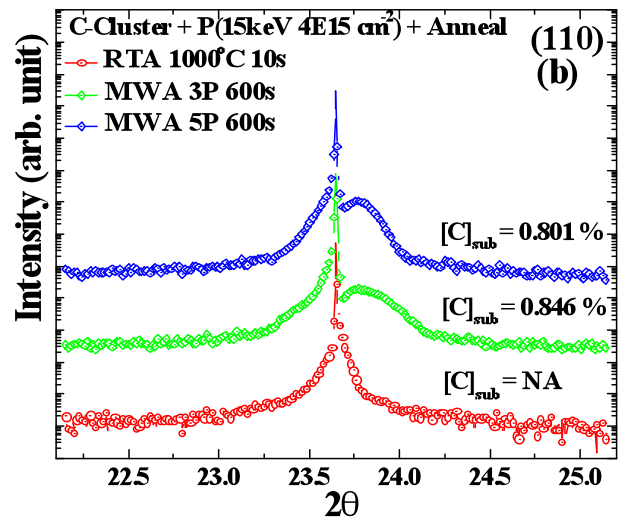
RTA (1,000 C, 10 s) give only low (<0.3%) substitutional C content.



Si(110):

MWA (480 -510 C, 600 s) gives lower C_{sub} (≈0.8%) content than Si (100).

RTA (1000 C, 10 s) results in low (<0.3%) substitutional C content.



Current Scientific

NARL

財團法人國家實驗研究院 國家奈米元件實驗室 National Nano Device Laboratories

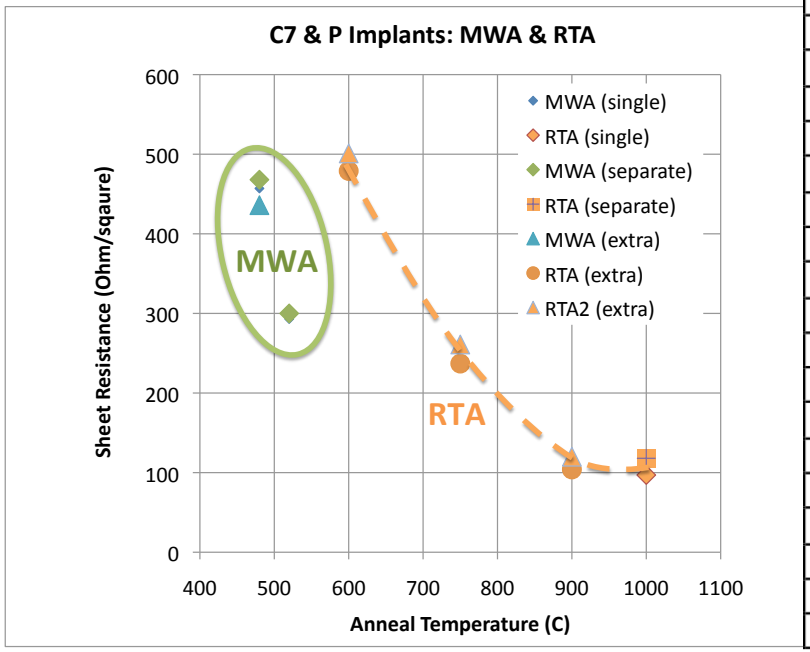
國立交通大學 National Chiao Tung University

日新イオン機器株式会社 NISSIN ION EQUIPMENT CO., LTD.

C_7 & P implants: C_{sub} & Sheet Resistance

Separate MWA after each implant gives high C_{sub} (1.44%).

RTA gives lower R_{sheet}, but poor C_{sub} >600 C.



Anneal Method	Anneal Conditions	C_{sub} (%)	Rs (ohms/sq.)	C_{sub} (%)	Rs (ohms/sq.)
C_7 implant, Single anneal					
		(100)		(110)	
RTA	900 °C 30s	1.47	na	nm	na
	1000 °C 10s	1.56	na	low (<0.5)	na
MWA	3P 600s	1.52	na	0.78	na
	5P 600s	1.57	na	0.99	na
C_7 + P implants, Single anneal after both implants are completed					
RTA	900 °C 30s	nm	nm	nm	nm
	1000 °C 10s	low	96.7	very low	134
MWA	3P 600s	1.27	457	0.85	770
	5P 600s	1.16	293	0.8	530
C_7 + P implants, Anneals after each implant					
RTA	1000 °C 10s	low	118	low	152
MWA	3P 600s	1.44	468	0.68	675
	5P 600s	1	300	0.63	634
Extra anneal after C_7 + P implants and MWA (3P 600s)					
	none	1.27	457	0.85	770
RTA	600 °C 30s	1.25	478.9	nm	nm
	750 °C 30s	1.18	237.1	nm	nm
	900 °C 30s	low	103.6	nm	nm
MWA	3P 600s	1.21	436.1	nm	nm
Extra anneal after C_7 + MWA (3P 600s) + P + MWA (3P 600s)					
	none	1.44	468	0.68	678
RTA	600 °C 30s	1.22	501.3	nm	nm
	750 °C 30s	1.11	260.7	nm	nm
	900 °C 30s	low	119.6	nm	nm
MWA	3P 600s	1.17	430.4	nm	nm

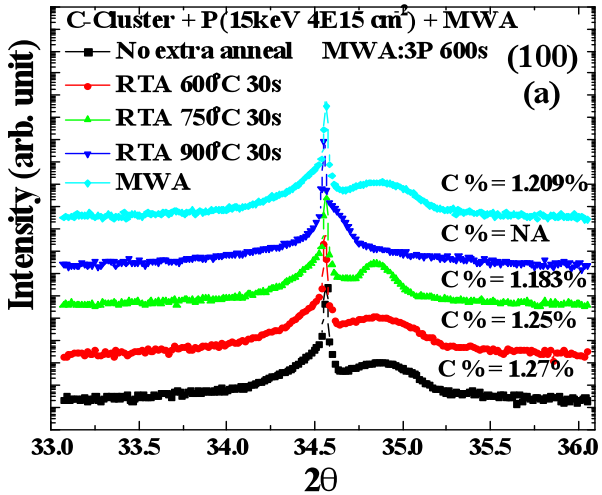
Current Scientific
NARL
NDL 財團法人國家實驗研究院 國家奈米元件實驗室 National Nano Device Laboratories
國立交通大學 National Chiao Tung University
日新イオン機器株式会社 NISSIN ION EQUIPMENT CO., LTD.

Extra Anneals: C_7 & P implants, XRD

With a single MWA after C_7 & P implants,

* Additional MWA keeps C_{sub} at ≈1.2%

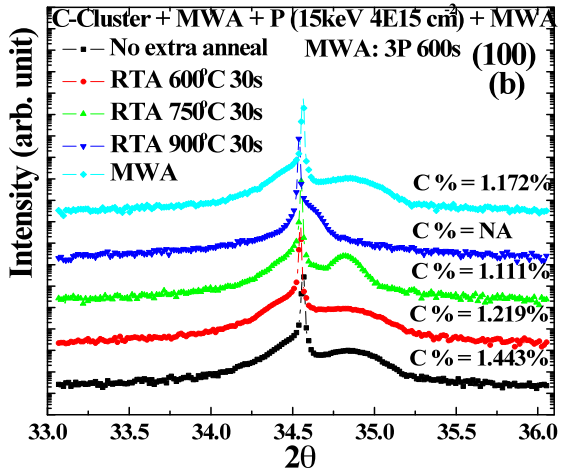
* RTA anneal >600 C reduces C_{sub}. C_{sub} is very low after RTA 900 C.



With a separate MWA after each C_7 & P implant,

* Additional MWA reduces C_{sub} from ≈1.4% to ≈1.2%.

* RTA anneal >600 C reduces C_{sub}. C_{sub} is very low after RTA 900 C.



Current Scientific

NARL

NDL 財團法人國家實驗研究院 國家奈米元件實驗室 National Nano Device Laboratories

國立交通大學 National Chiao Tung University

日新イオン機器株式会社 NISSIN ION EQUIPMENT CO., LTD.

Summary

1. MWA (≈500 C) is more effective than RTA (600-1000 C) for realizing high C strain and P activation for shallow junction (nMOS SDE) formation.

2. Si(100) much better than Si(110) for α-Si re-growth.

3. Dense twin-like dislocations seen near junction surfaces at high C concentrations for both MWA & RTA.

4. Additional RTA anneals >600 C result in lower R_{sheet} (diffusion) but loss of C strain (C_{sub}).

Current Scientific

NARL

財團法人國家實驗研究院 國家奈米元件實驗室 National Nano Device Laboratories

國立交通大學 National Chiao Tung University

日新イオン機器株式会社 NISSIN ION EQUIPMENT CO., LTD.

Key Acknowledgements

Yu-Lun Lu
National Chiao Tung U.

Yau-Jen Lee
Nano Device Labs.