Influence of metallic contamination on CMOS image sensors and analytical techniques

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Outline

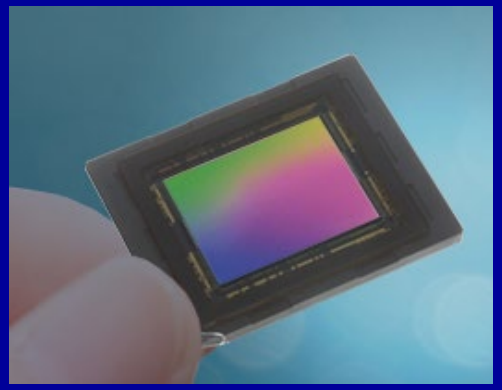
Introduction
- Influence of metal impurities on CMOS image sensors

Metallic contamination control in CMOS sensor processing

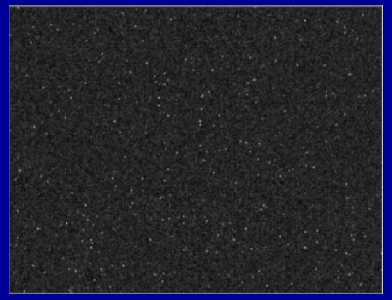
- Analysis of surface metallic contamination
- Behavior of surface metal penetrating silicon
- Measurements of electronic defects due to metal impurities

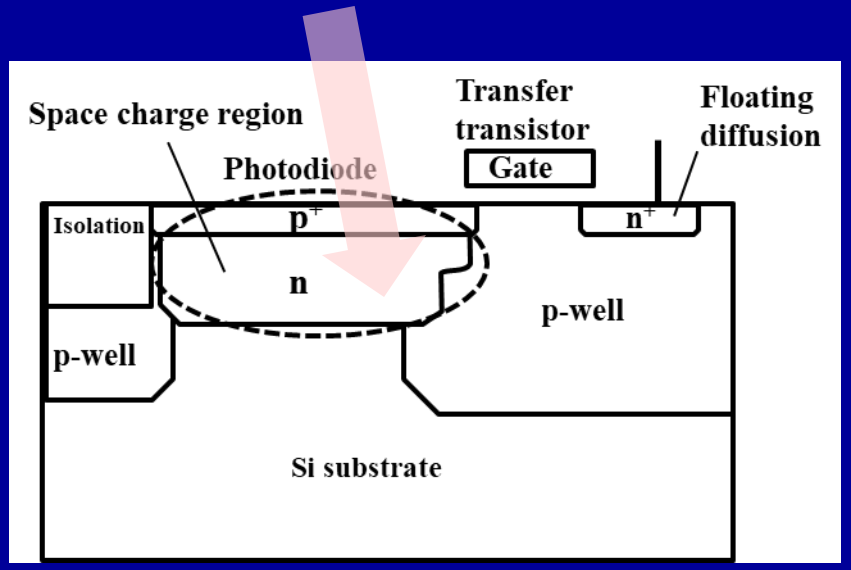
Summary

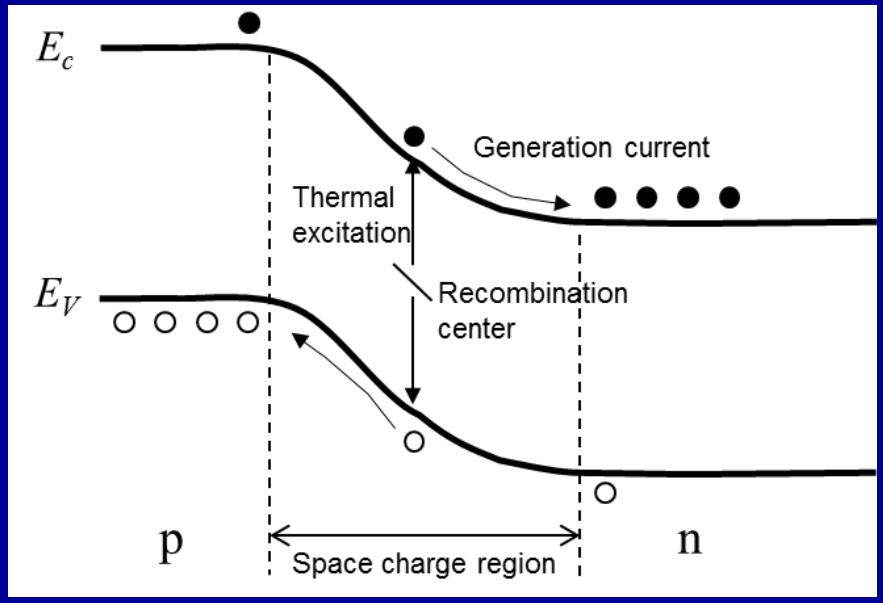
Carrier generation in CMOS image sensors



White spots



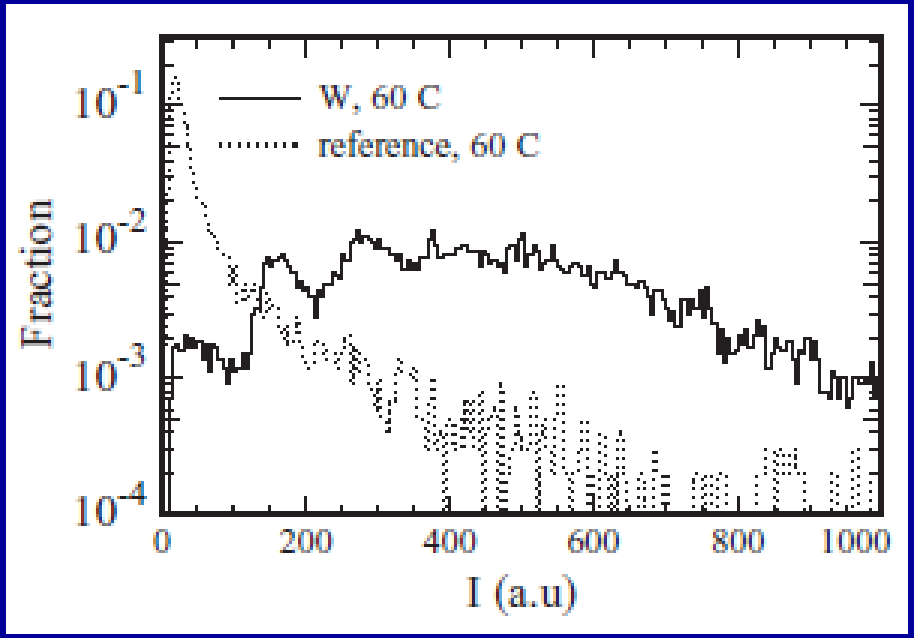




Dark current is generated by carrier recombination centers due to metal or crystal defects in space charge region.

Influence of Metal Impurities on CMOS imagers

Histogram of dark current in CMOS image sensors



F. Russo, ECS Journal of Solid State Science and Technology, 6(5), P217 (2017).

Dark current is generated by metal-related recombination centers in space charge region.

Influence of Metal Impurities on CMOS image sensors

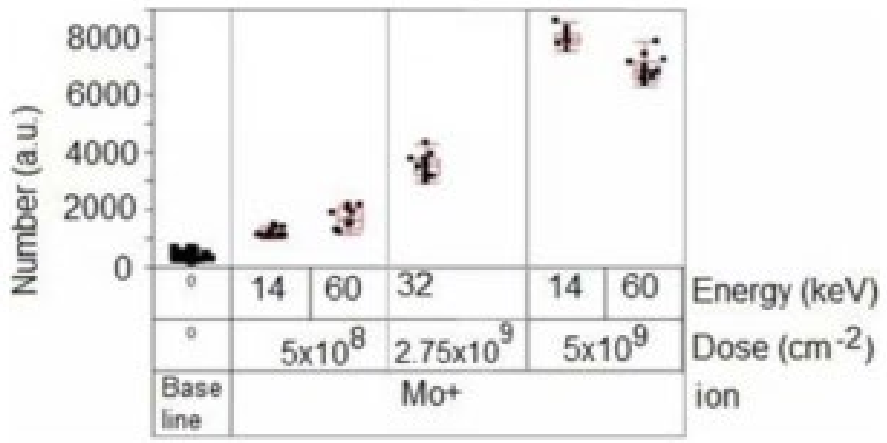
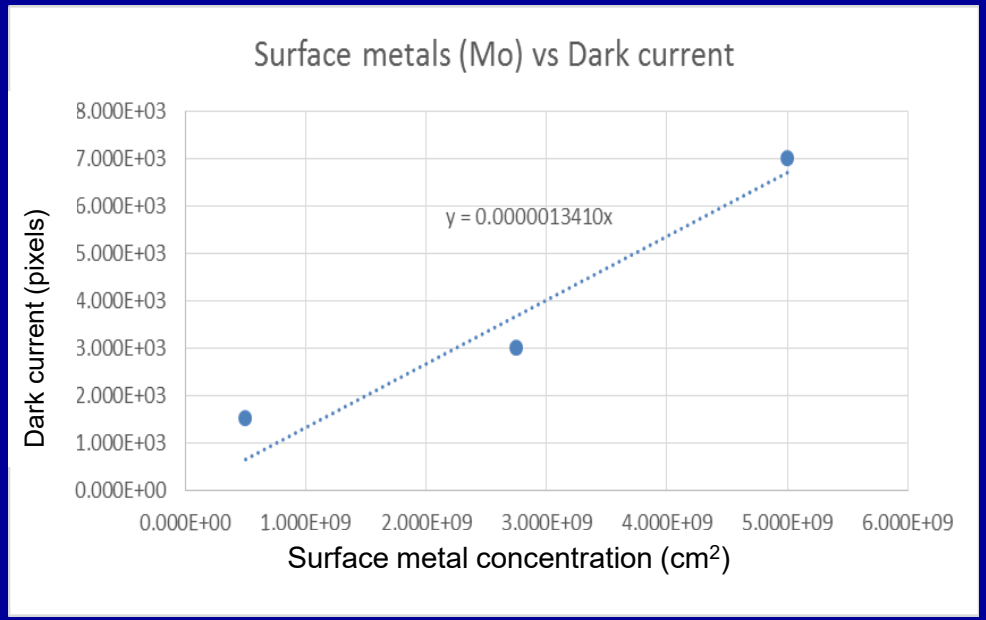


Figure 8. Number of hot pixels versus Mo implantation energy and dose. "Baseline" indicates the uncontaminated sample.

F. Russo, ECS Journal of Solid State Science and Technology, 6(5), P217 (2017).

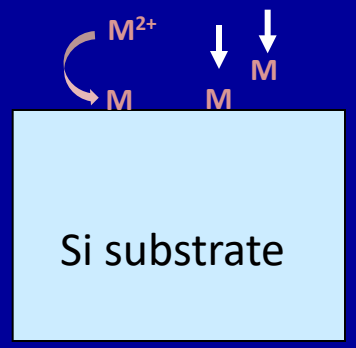


IRDS 2018 Yield Enhancement, White paper.

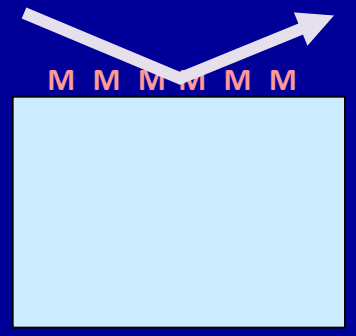
Overview of metallic contamination control

M: Metals

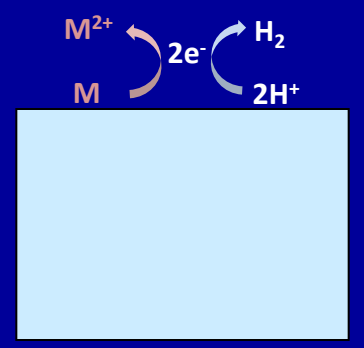
Deposition



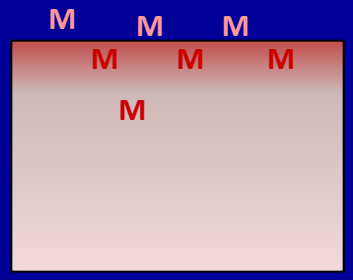
Detection and Analysis



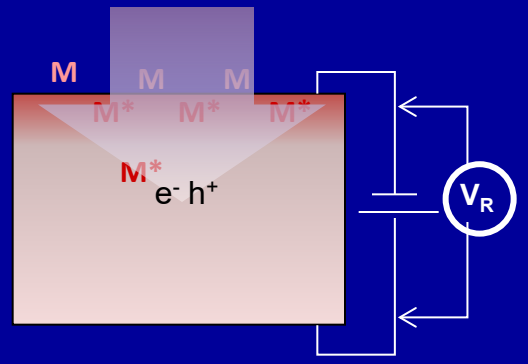
Removal



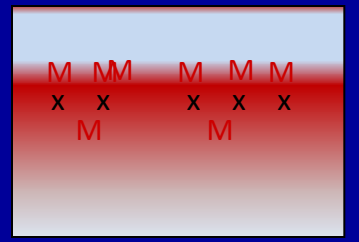
Penetration and Diffusion



Detection of electrically activated metals



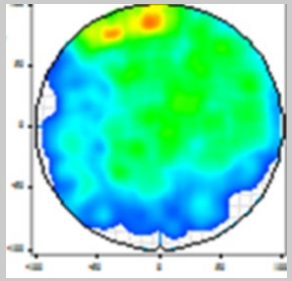
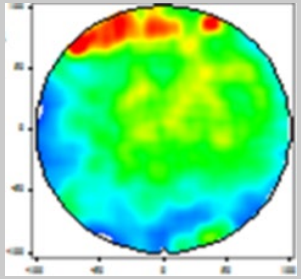
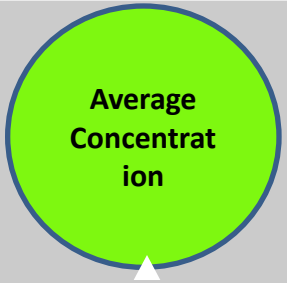
Gettering

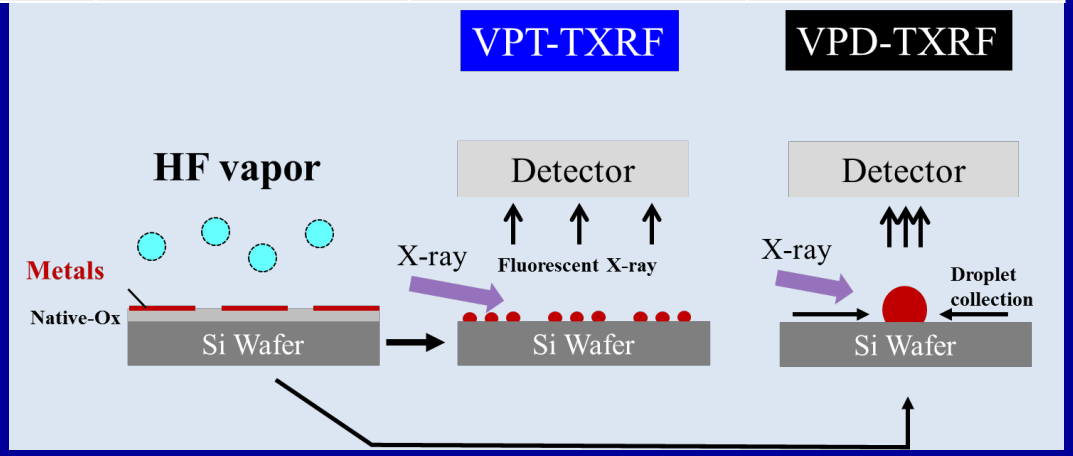


Detection and Analysis of Surface Metal Contamination

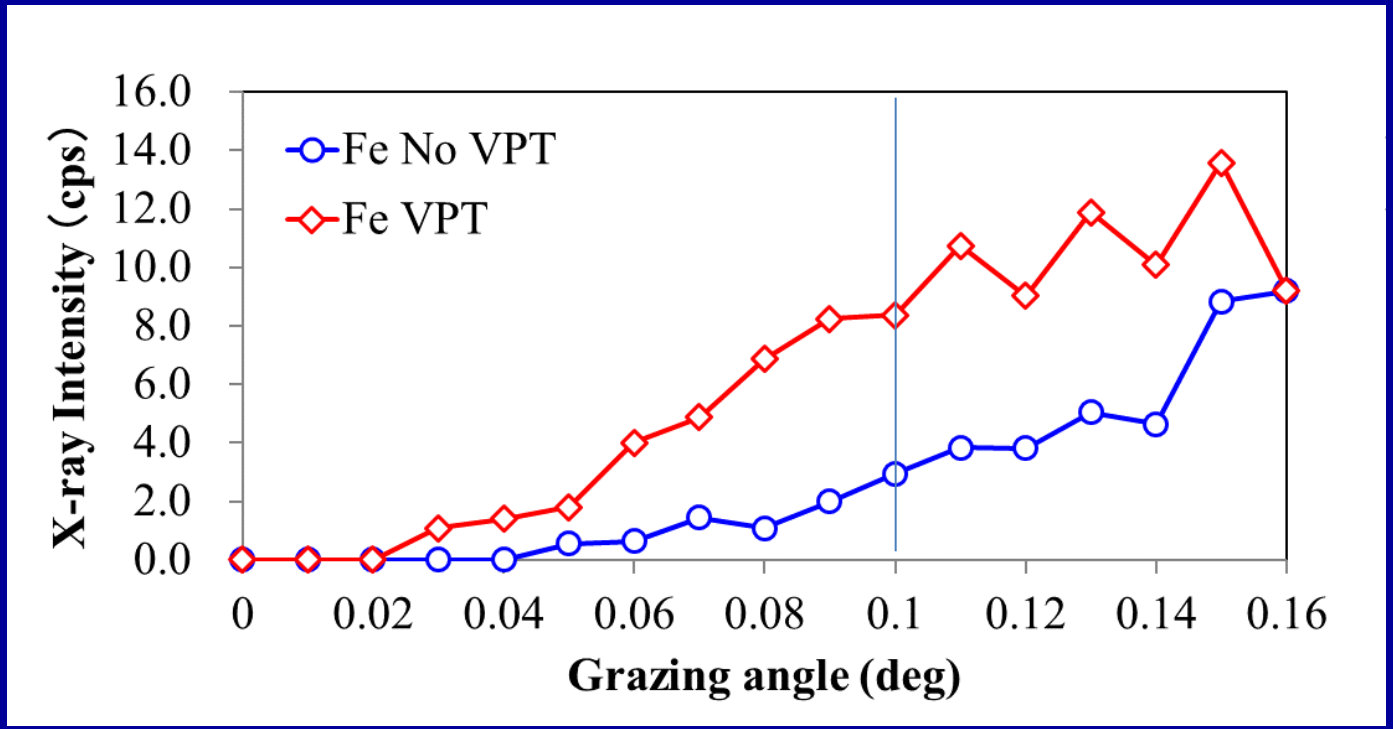
Surface metallic contamination measurement techniques

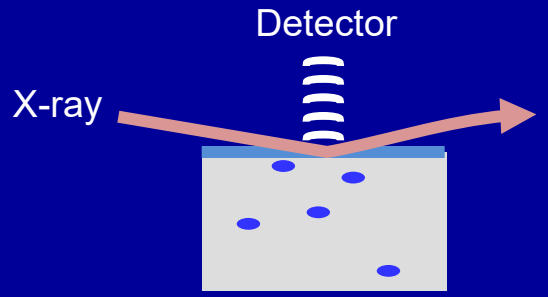
TXRF :Total Reflection X-ray Fluorescence
VPT: Vapor phase treatment
VPD :Vapor phase decomposition

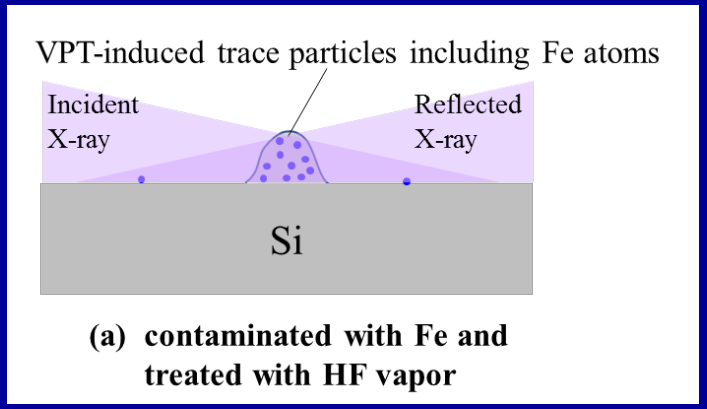
	TXRF	VPT-TXRF	VPD-TXRF ICP-MS
Spatial information	Yes	Yes	No
LLD (atoms/cm^2)	1～3×10^{10}	3～9×10^9	2～5×10^7
In-wafer distribution of surface metal concentration			



Enhancement of the detection sensitivity of TXRF by vapor phase treatment (VPT)

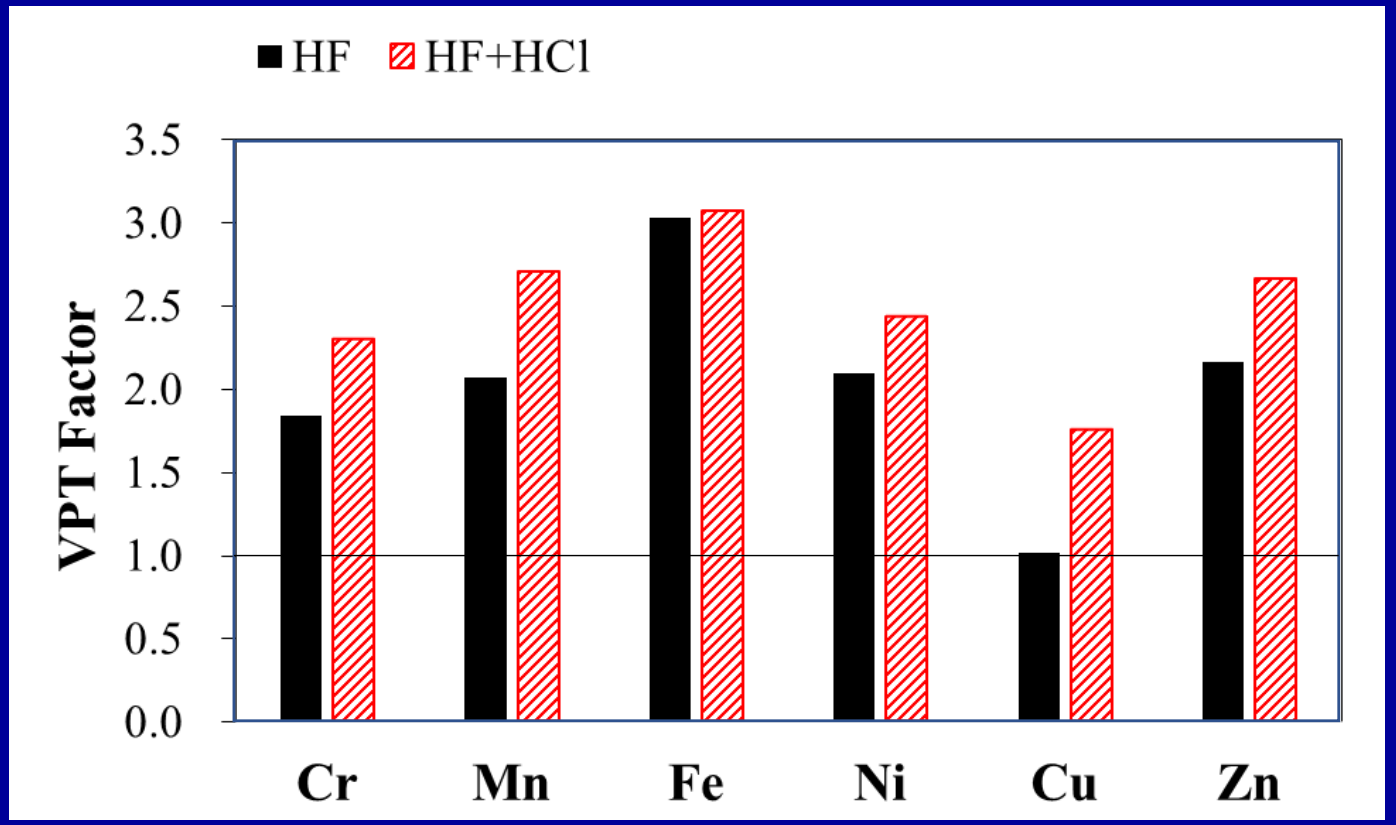






R. Ohno and K. Saga, Solid State Phenomena, Vol. 282, pp 309-313

VPT factors of wafers treated by HF vapor or HF/HCl vapor



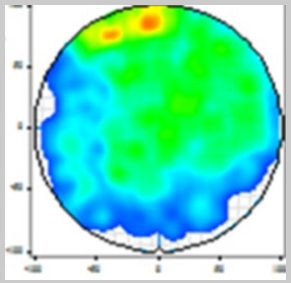
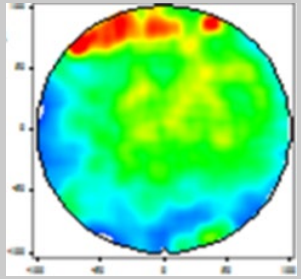
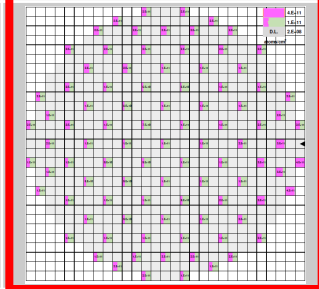
The sensitivities of all the metals including Cu has been enhanced by treating with HF/HCl vapor prior to TXRF measurements.

R. Ohno and K. Saga, Solid State Phenomena, Vol. 282, pp 309-313

Surface metallic contamination measurement techniques

TXRF :Total Reflection X-ray Fluorescence
VPT: Vapor phase treatment
VPD :Vapor phase decomposition
LA: Laser Ablation
ICP-MS: Inductively coupled plasma mass spectrometry

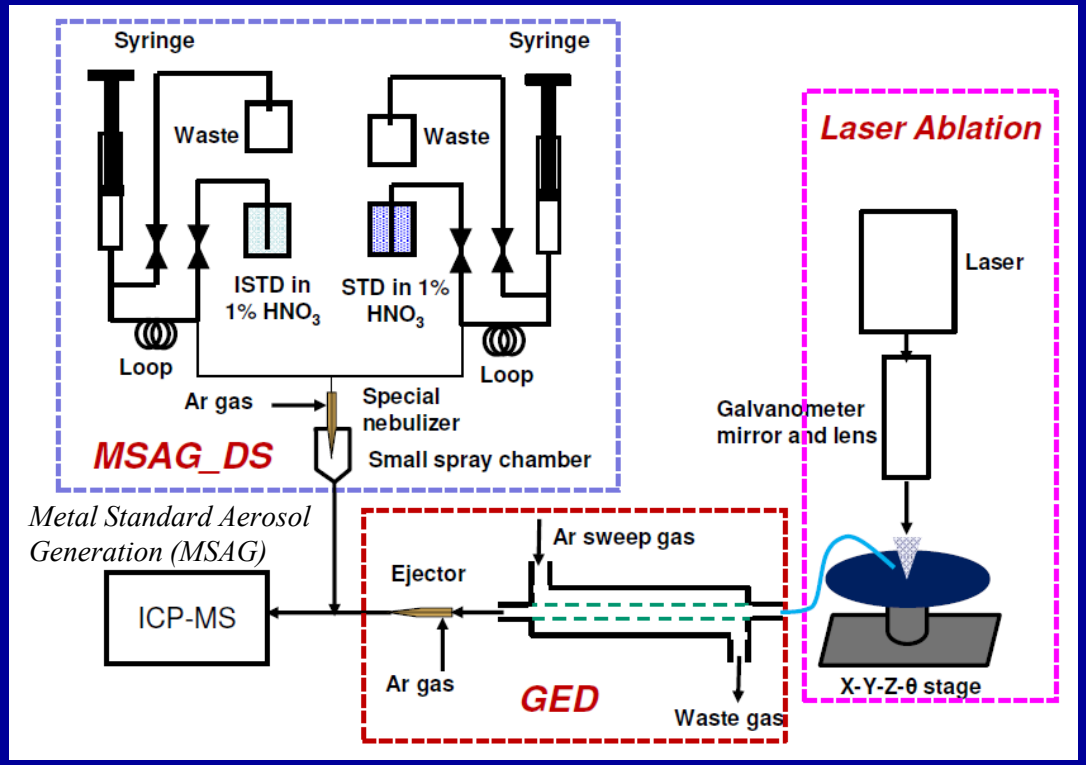
LA-ICP-MS with high detection sensitivity has been introduced.

	TXRF	VPT-TXRF	VPD-TXRF ICP-MS	LA-ICP-MS
Spatial information	Yes	Yes	No	Yes
LLD (atoms/cm^2)	1～3×10^{10}	3～9×10^9	2～5×10^7	1~10×10^7
In-wafer distribution of surface metal concentration			Average Concentration	

Surface metallic contamination measurement techniques

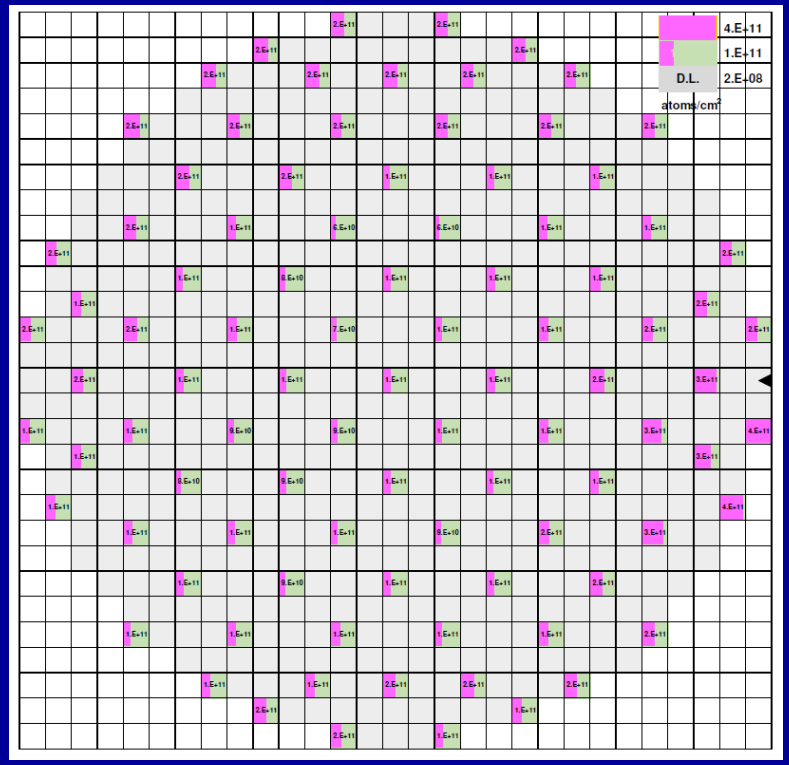
LA-ICP-MS with high detection sensitivity has been introduced.

LA-ICP-MS



Gas Exchange Device (GED)

Zn concentration mapping in 300mm wafers

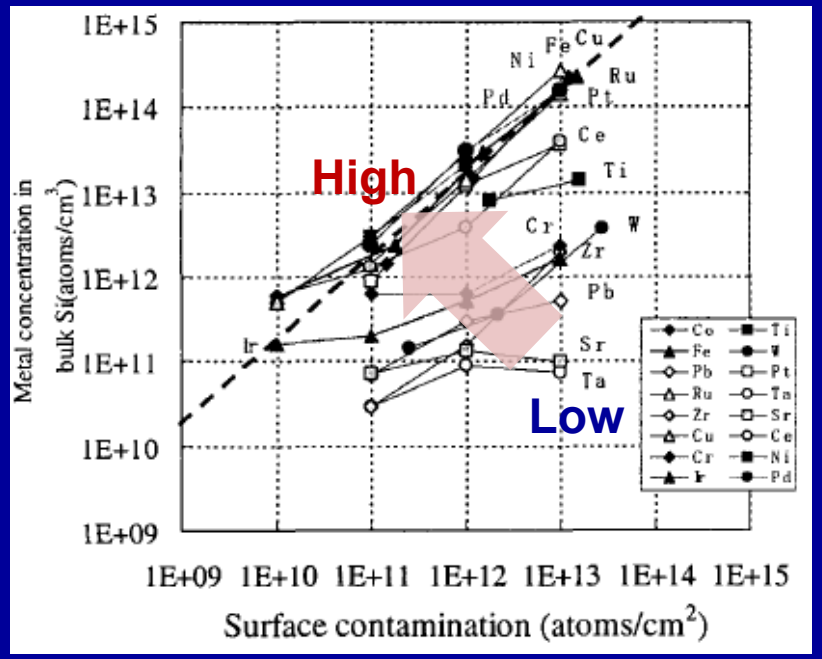


93 spots with 10 mm x 10 mm scanning

K. Kawabata, et.al, ECS Transactions,114, 35, 2024

Behavior of surface metal penetrating silicon

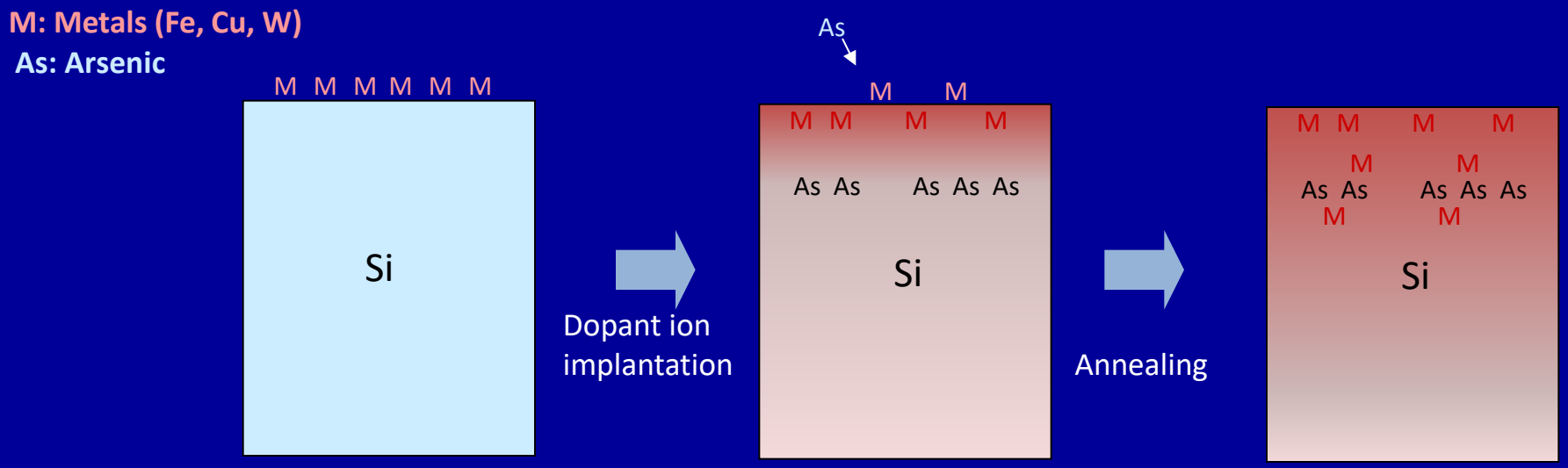
Metal diffusion in Si



H. Sakurai, et.al, ISSM 2001 Pages: 163 - 166

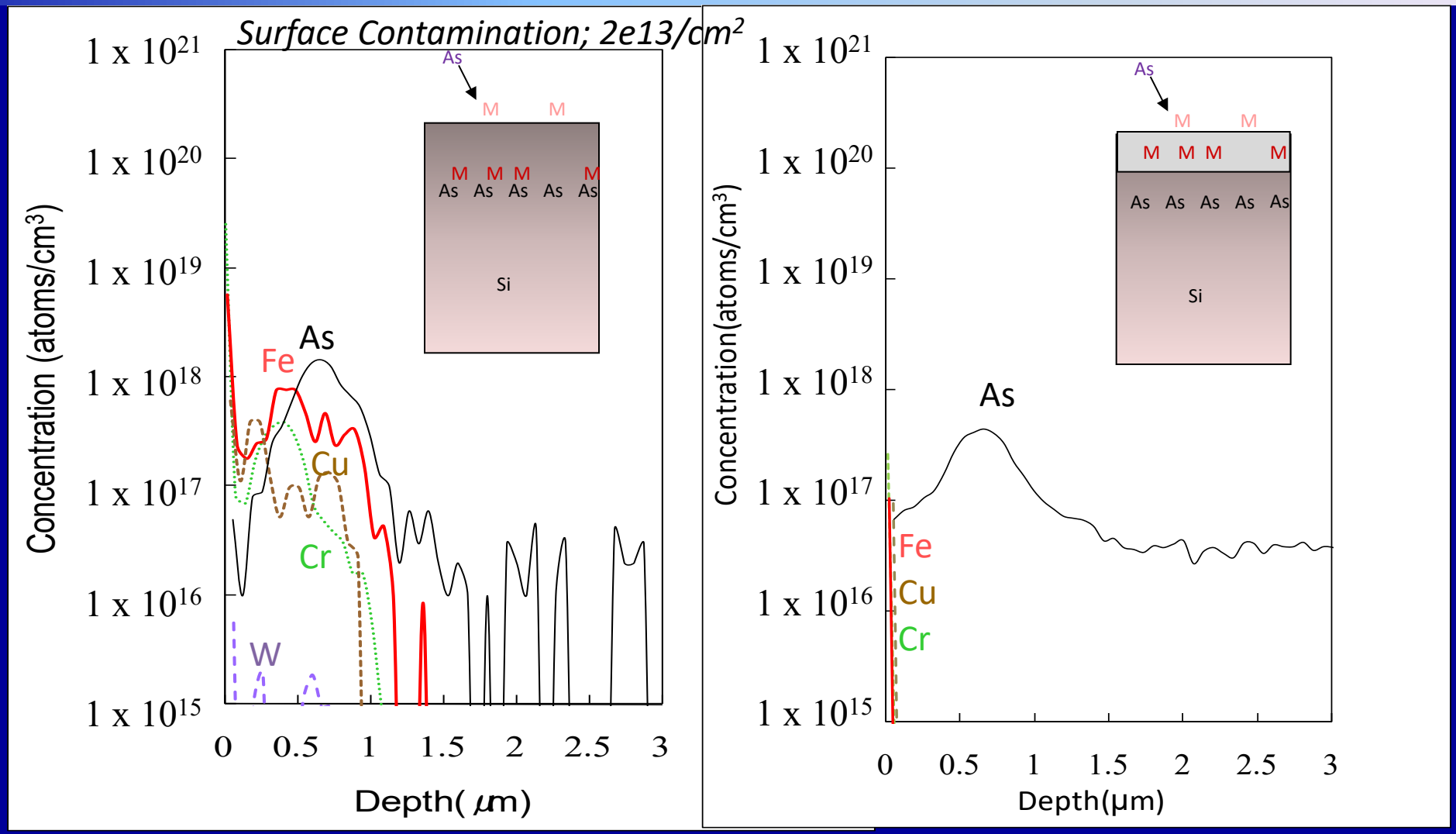
Diffusion coefficients of various metal species are reported.

Schematic illustration of metal penetration and diffusion



Surface metal impurities penetrate silicon by collision with dopant ions in ion implantation as well as by annealing.

SIMS profiles of near-surface metals in silicon with/without SiO_2 after implantation (no annealing)



(a) Without SiO_2

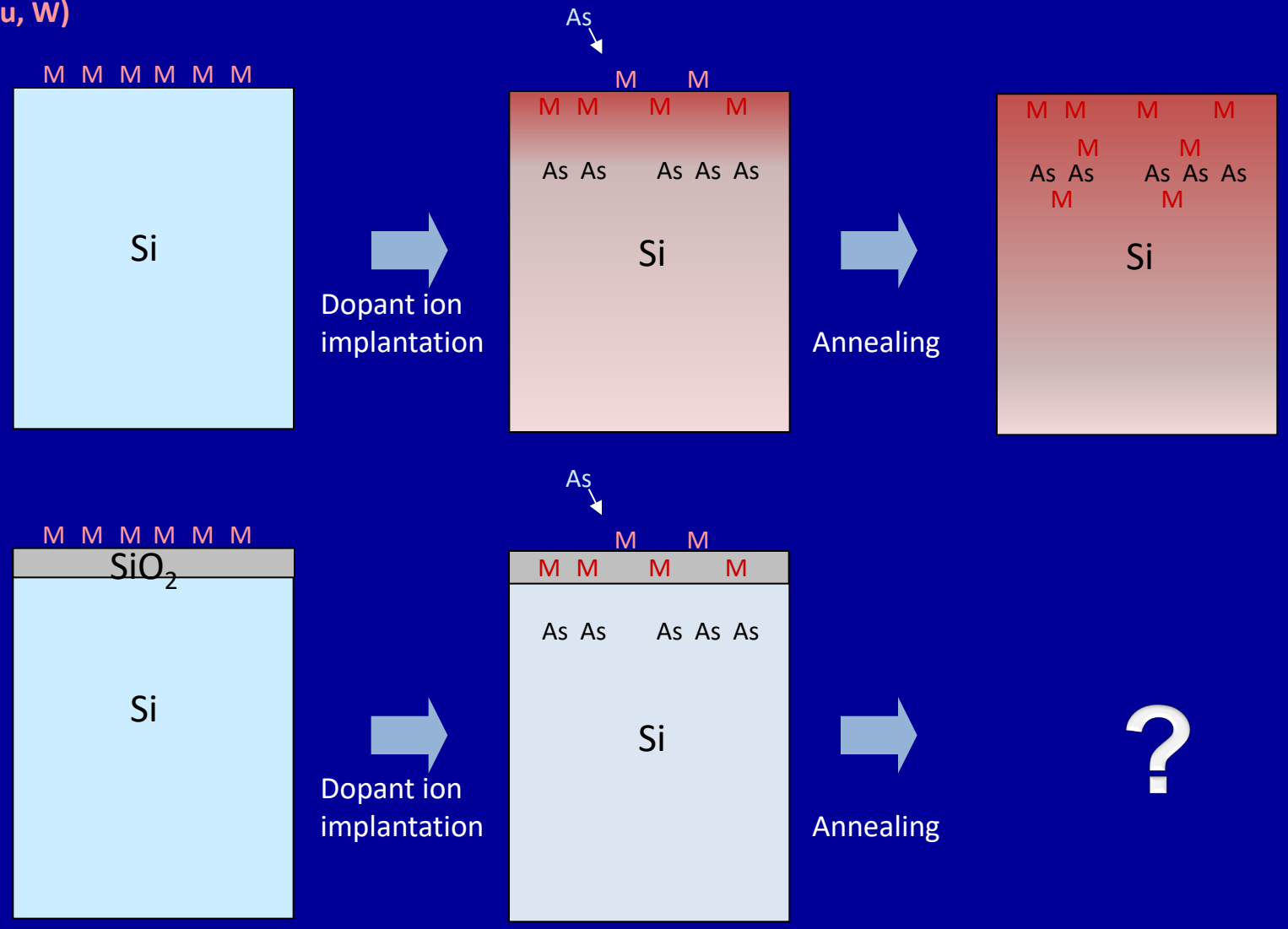
(b) With 20nm SiO_2

K. Saga, ECS Journal of Solid State Science and Technology, 4 (5) P131-P136 (2015)

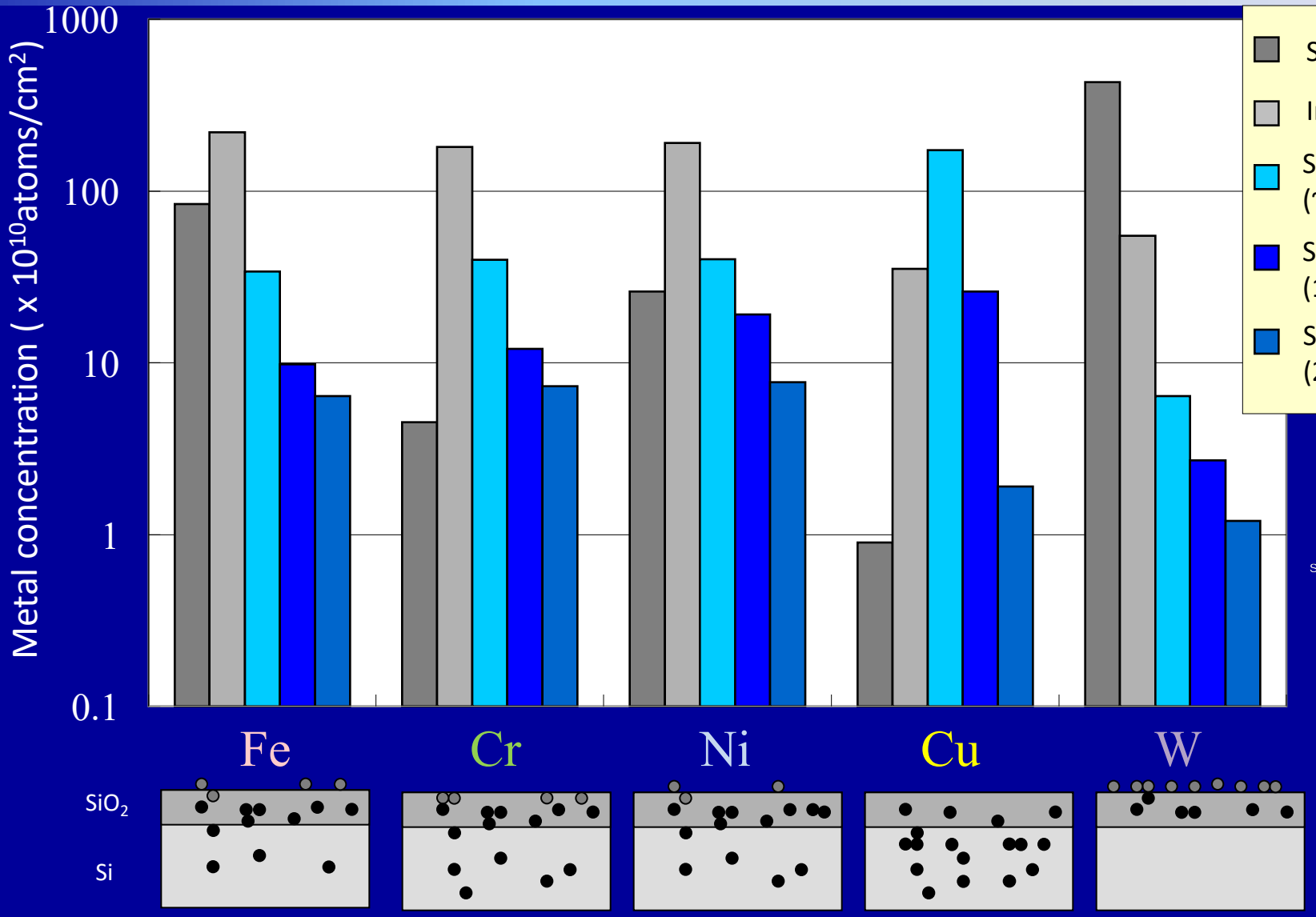
Schematic illustration of metal penetration and diffusion

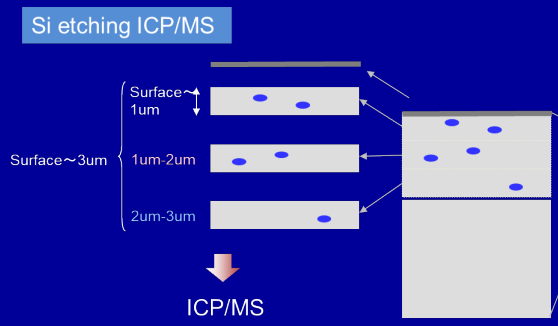
M: Metals (Fe, Cu, W)

As: Arsenic



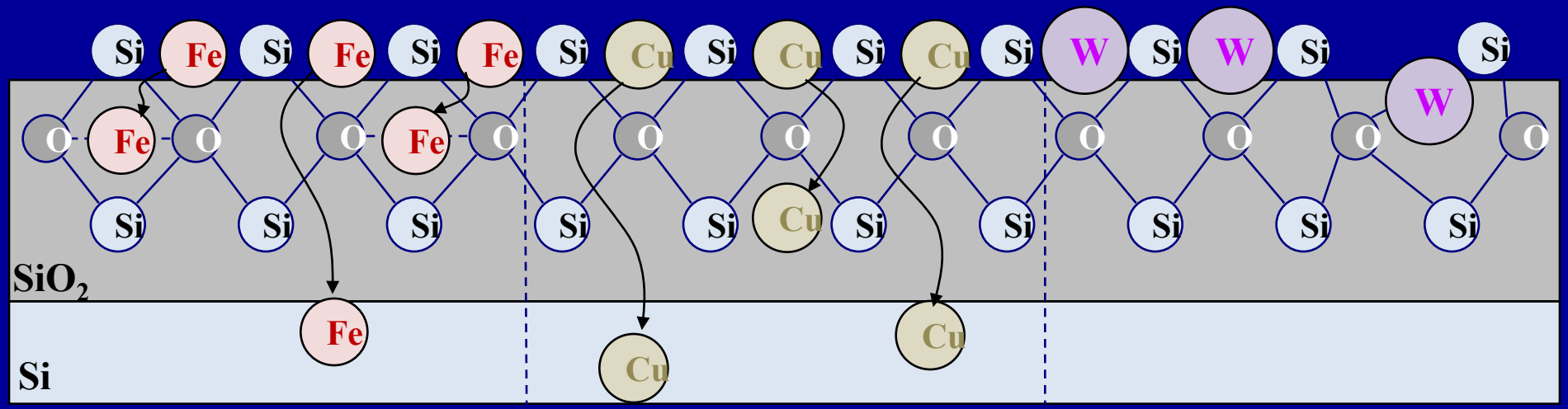
Sub-surface metal concentration after ion implantation followed by annealing (900°C,20min)





K. Saga, ECS Journal of Solid State Science and Technology, 4 (5) P131-P136 (2015)

Possible Model for metals penetrating silicon and silicon oxide

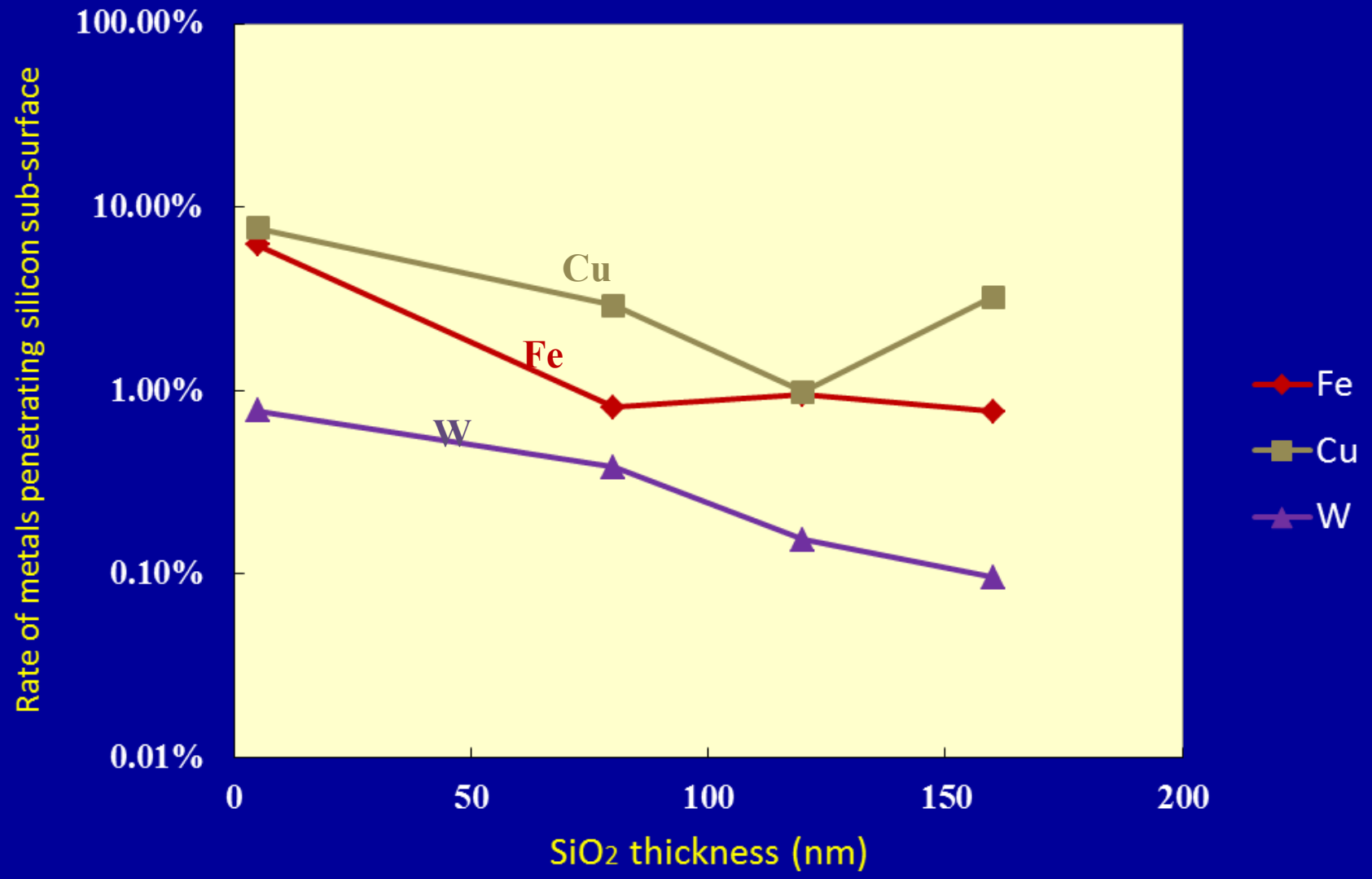


Oxide formation enthalpy and molecular weight

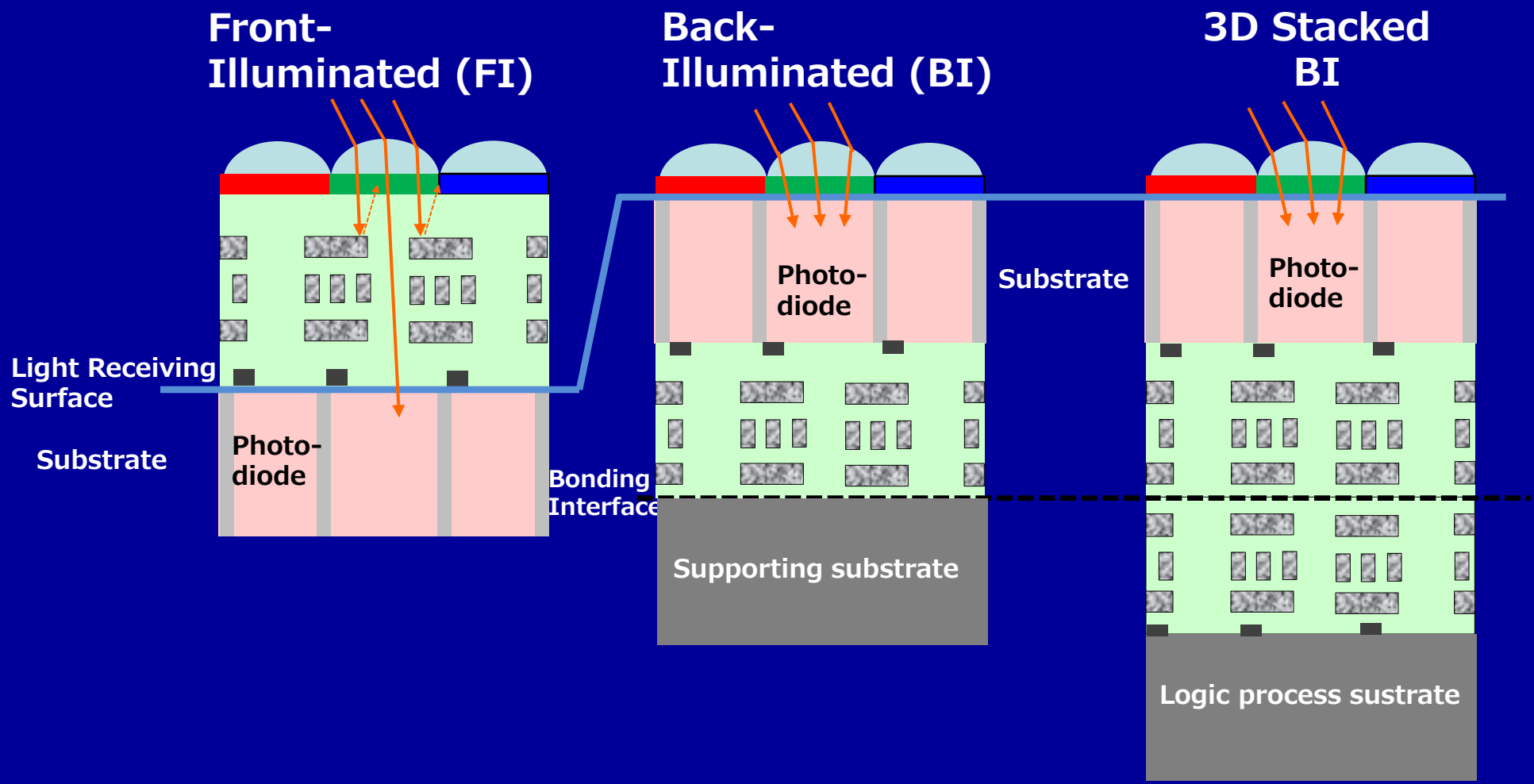
Elements	Fe	Cr	Ni	Cu	W	As
Oxide	Fe_2O_3	Cr_2O_3	NiO	CuO	WO_3	
⊿Hf0 (kcal/g.e.)	-33	-45	-29	-19	-34	
Molecular weight	55.9	52	58.7	63.6	184	74.9

Metal penetration probability

(As implanted and annealed at 950ºC, for 10 min.)



Progress of CMOS Image Sensor

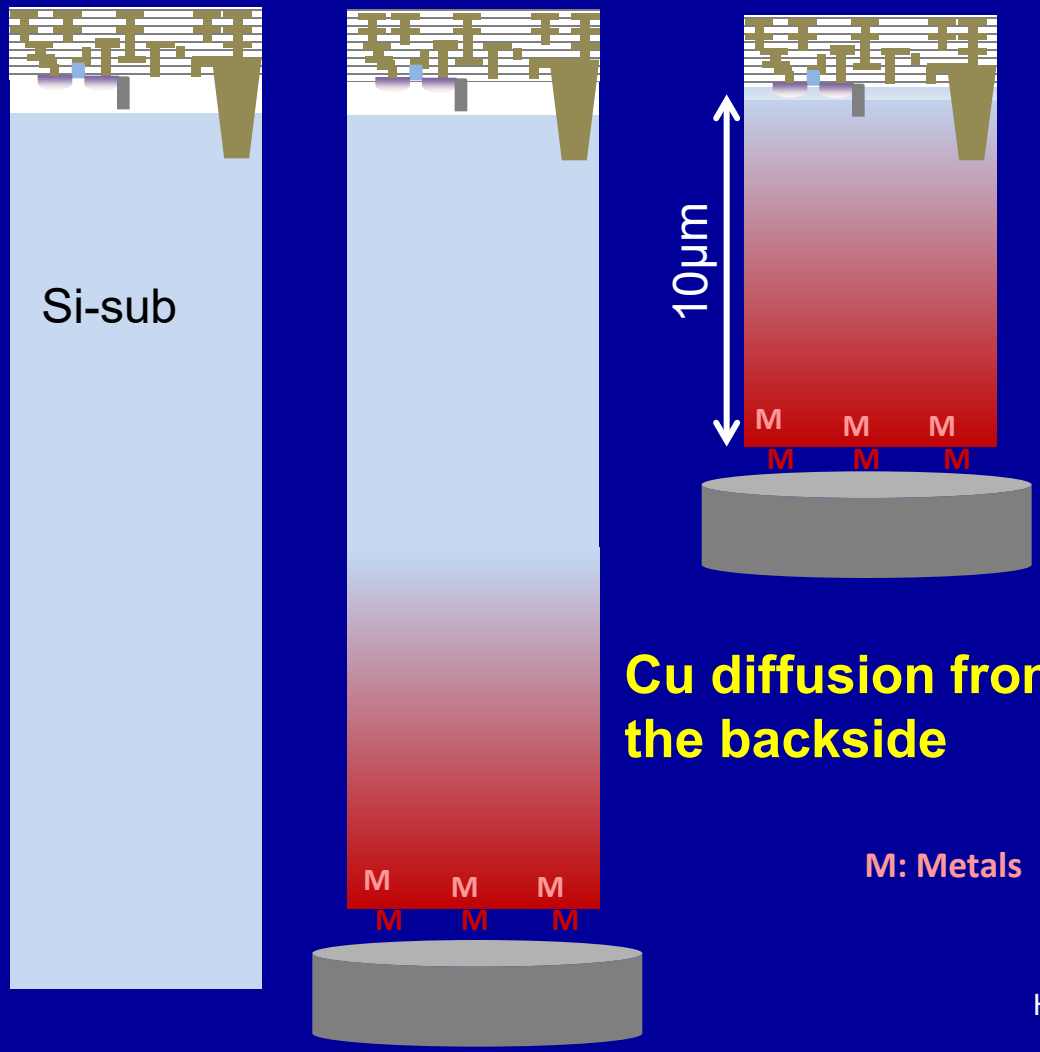


High Sensitivity

Smaller chip
Additional Functions

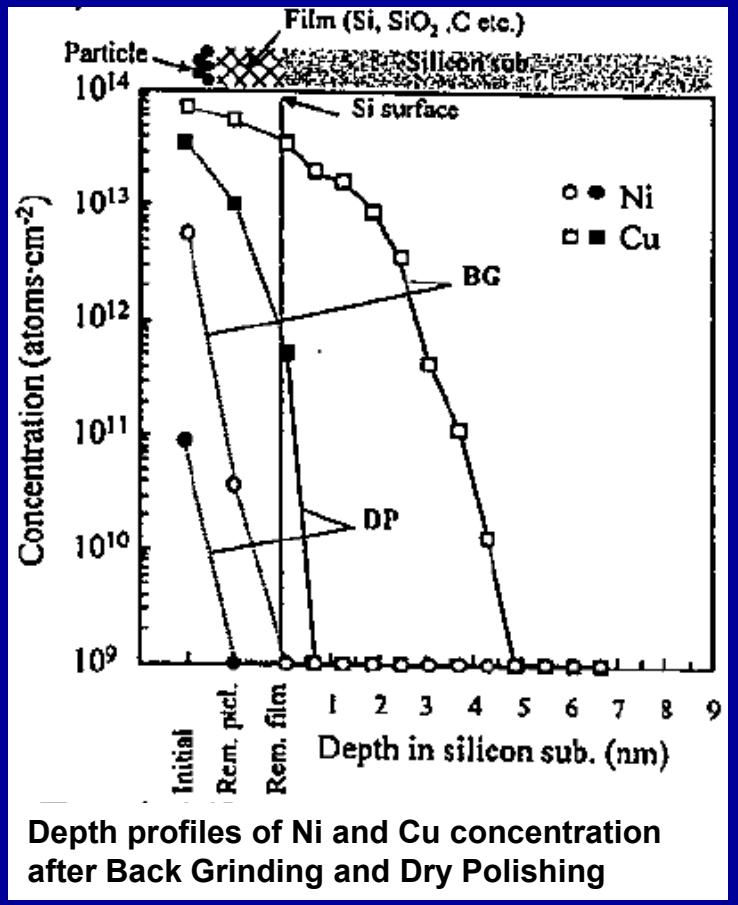
Y. Kagawa, IEDM2016

Cu diffusion in wafer thinning process



Cu diffusion from the backside

M: Metals

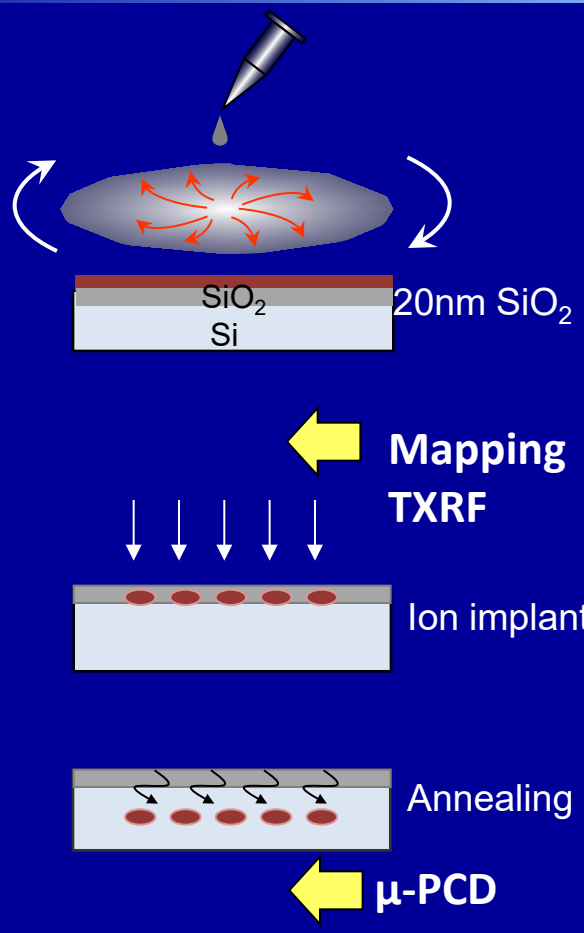


Depth profiles of Ni and Cu concentration after Back Grinding and Dry Polishing

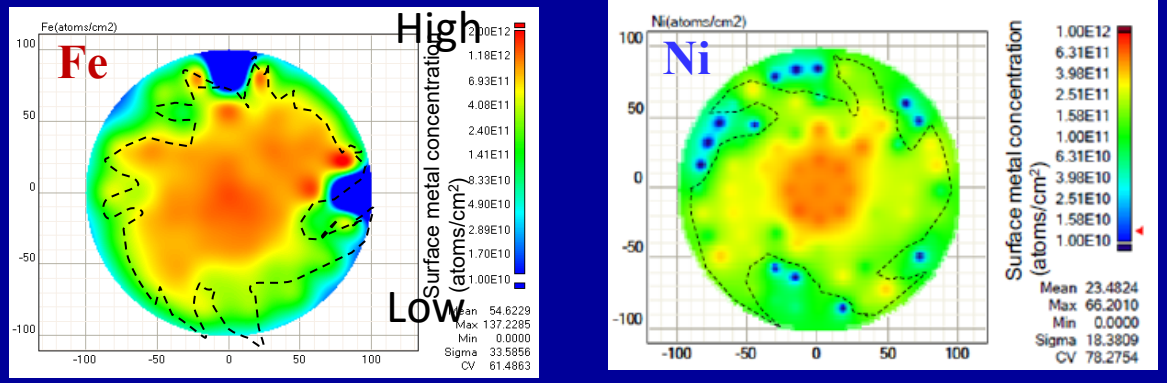
Hozawa, et.al, JSAP 56th Meeting, 1p-S-4, No.2, p.825 (2009)

Recombination centers in Silicon due to Surface Metals Penetrating Silicon

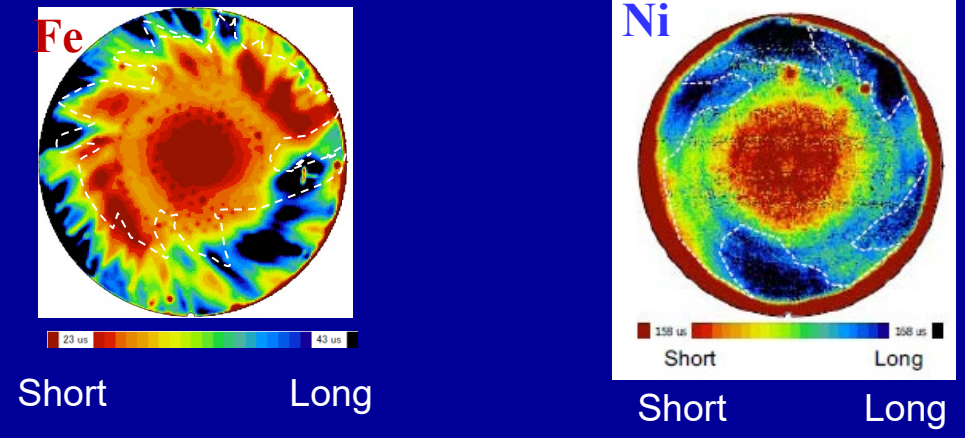
Carrier Recombination



Average concentration: 2 ×10^{11}atoms/cm^2



(a) In-wafer distribution of the surface metal concentration

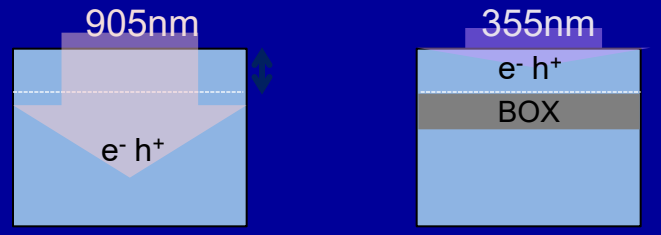


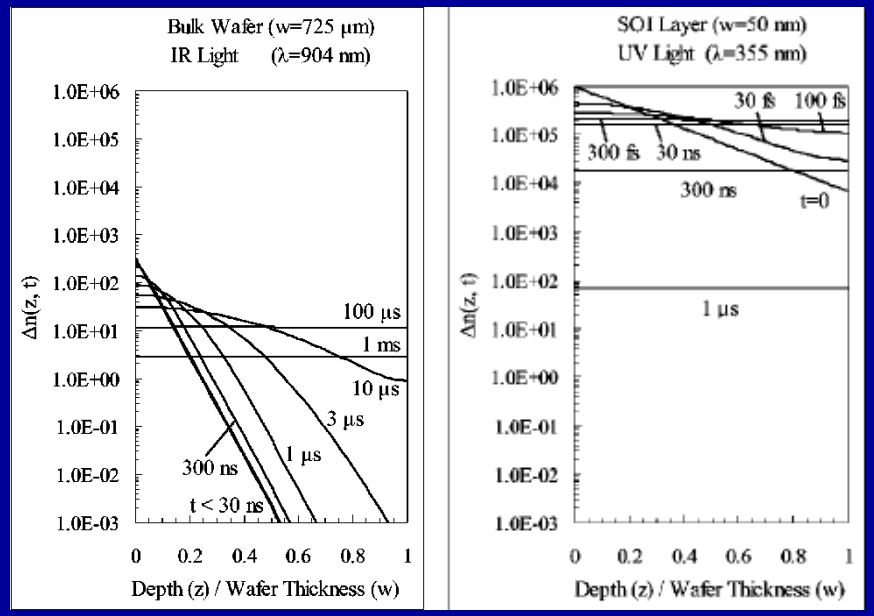
(b) Recombination lifetime distribution

K. Saga, ECS Journal of Solid State Science and Technology, **4** (5) P131-P136 (2015)

Near-Surface Minority Carrier Lifetime

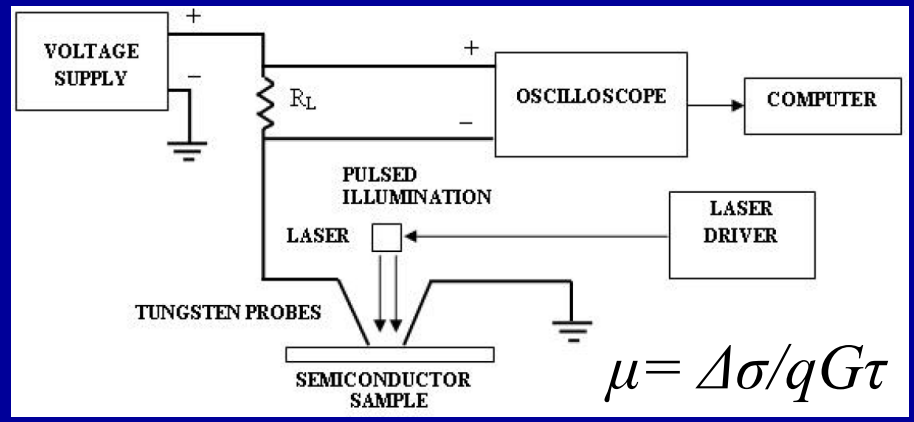
Short-wavelength Microwave Photoconductive Decay (μ-PCD)

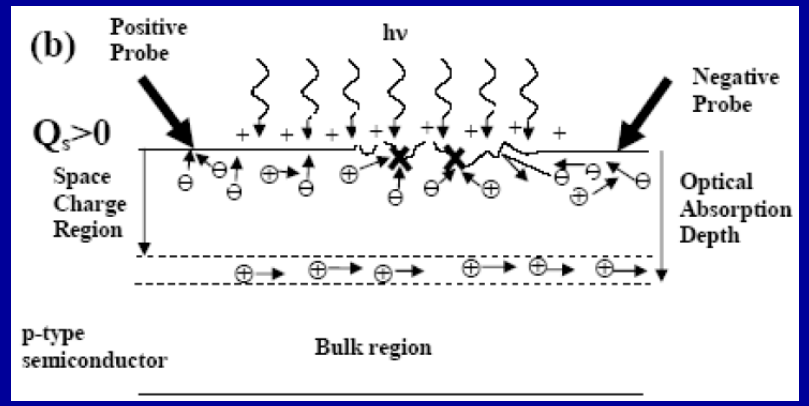




S. Sumie, Journal of The Electrochemical Society, **152,** G99-G106 (2005)

Temporary Contact Photoconductive Decay (PCD)



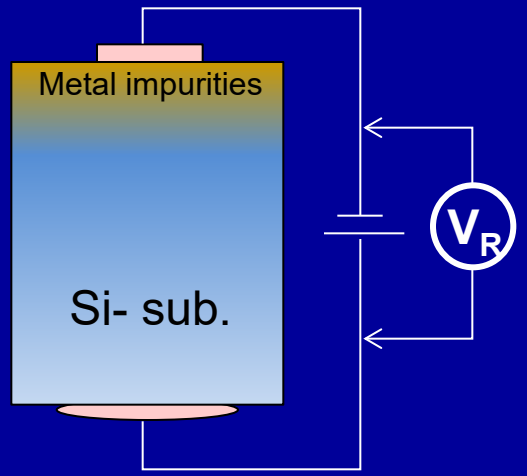


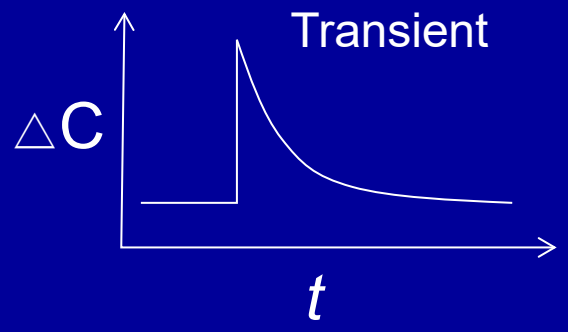
P. Drummond, et.al, *ECS Transactions, 25 (5) 361-366 (2009)*

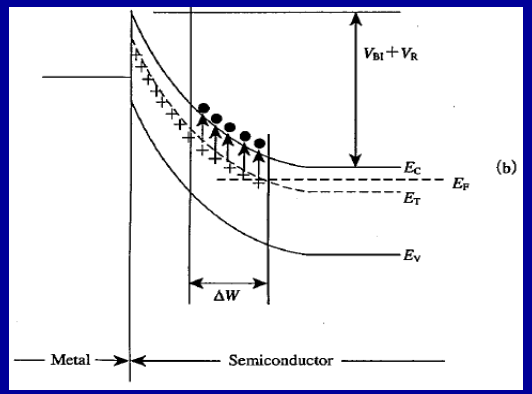
Detection of Metal-Related Deep Levels in Silicon

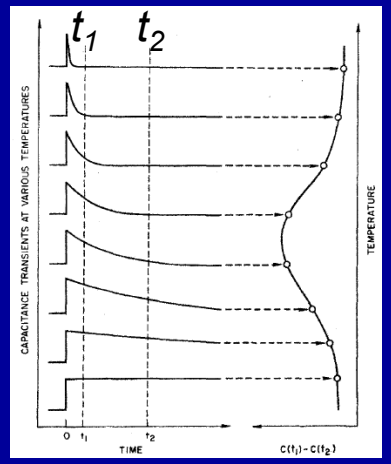
Deep Levels in CZ-Silicon

Deep level transient spectroscopy (DLTS)





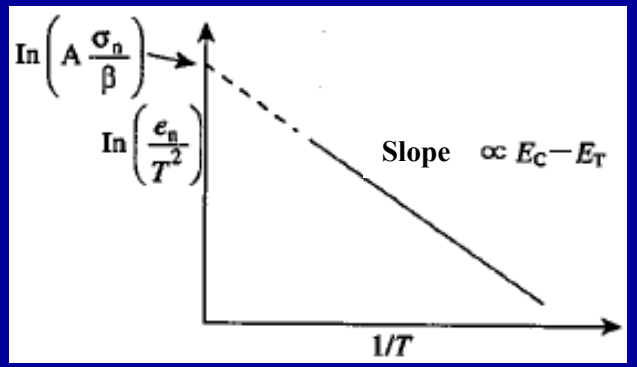




Temperature

Time $C(t_1)$-$C(t_2)$

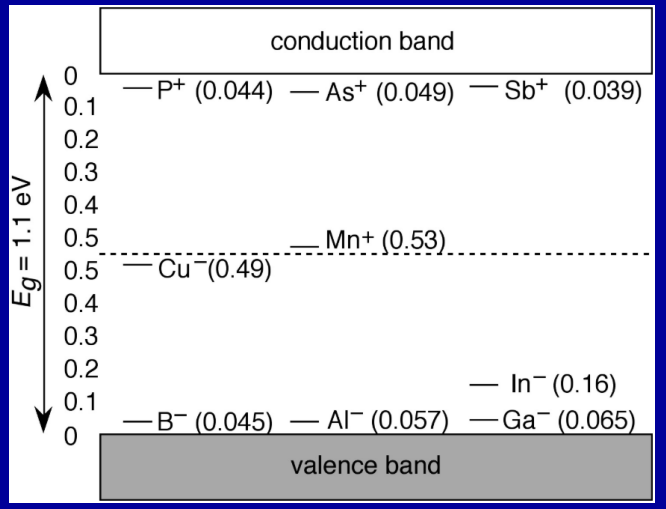
Arrenius plot



Deep Levels in CZ-Silicon

Charge state	Level [eV]	T_{peak} [K]	Capture cross-section [cm^2]	Assignment	Ref.
$Ti^{-/0}$	$E_C - 0.09$	49	$\sigma_n^0 = \sim 3 \times 10^{-14}$**	Int.	[13]
$Ti^{0/+}$	$E_C - 0.27$	165	$\sigma_n^+ = 8 \times 10^{-15}$**	Int.	[13]
$Ti^{+/++}$	$E_V + 0.28$	200	$\sigma_p^+ = 4.4 \times 10^{-17} \exp(-0.037/kT)$**	Int.	[13]
$V^{-/0}$	$E_C - 0.20$	122	$\sigma_n^0 = 1.2 \times 10^{-16}$	Int.	[12,15]
$V^{0/+}$	$E_C - 0.45$	224	$\sigma_n^+ = 5.3 \times 10^{-15}$	Int.	[12,15]
$V^{+/++}$	$E_V + 0.34$	260	$\sigma_p^+ = 1.2 \times 10^{-16} \exp(-0.12/kT)$	Int.	[12,15]
$Cr^{0/+}$	$E_C - 0.22$	120	$\sigma_n^+ = 1.4 \times 10^{-14}$	Int.	[**]
$(Cr^{+/++}\text{-}B^-)^{0/+}$	$E_V + 0.29$	159	$\sigma_p^0 = 2.1 \times 10^{-15}$	Pair	[**]
$Mn^{-/0}$	$E_C - 0.12$	68	$\sigma_n^0 = 3.4 \times 10^{-15}$	Int.	[11]
$Mn^{0/+}$	$E_C - 0.41$	219	$\sigma_n^+ = 5.2 \times 10^{-15}$	Int.	[11]
$(Mn^{+/++}\text{-}B^-)^{0/+}$	$E_C - 0.50$	270	—	Pair	[11]
$Mn^{+/++}$	$E_V + 0.32$	220	$\sigma_p^+ = 2.7 \times 10^{-17} \exp(-0.064/kT)$	Int.	[11]
$(Fe^{0/+}\text{-}B^-)^{-/0}$	$E_C - 0.29$	155*	—	Pair	[16]
$Fe^{0/+}$	$E_V + 0.40$	252	$\sigma_p^0 = 1.8 \times 10^{-16} \exp(-0.038/kT)$**	Int.	[7,8]
$(Fe^{+/++}\text{-}B^-)^{0/+}$	$E_V + 0.10$	59	$\sigma_p^0 = \sim 1 \times 10^{-14}$**	Pair	[7,8]
$Co^{-/0}$	$E_C - 0.40$	220	$\sigma_n^0 = 1.6 \times 10^{-15}$	Sub.	[5,10]
$Co^{0/+}$	$E_V + 0.23$	114	$\sigma_p^0 = 1.8 \times 10^{-14}$	Sub.	[5,10]
$Ni^{-/0}$	$E_C - 0.45$	253	$\sigma_n^0 = 1.8 \times 10^{-16}$**	Sub.	[9,14]
$Ni^{0/+}$	$E_V + 0.16$	91	$\sigma_p^0 = 9.7 \times 10^{-15}$**	Sub.	[9,14]

* : T_{peak} is estimated from emission rate determined in the range 100-125 K by using single shot technique.
**: Unpublished results.

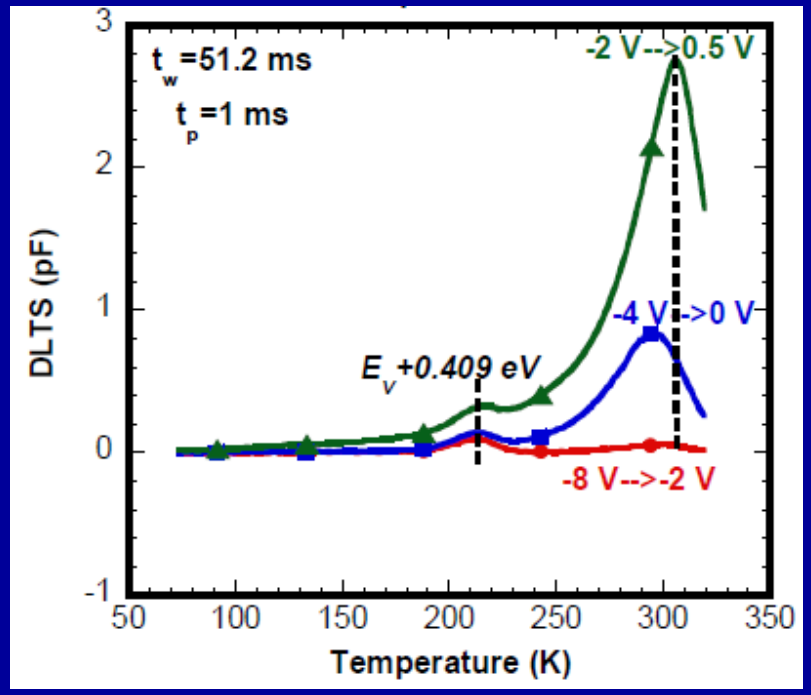


Dark current $i_1 = \dfrac{q n_i A_{min} v_{th}}{2\cosh\left(\dfrac{E_t - E_i}{kT}\right)}$

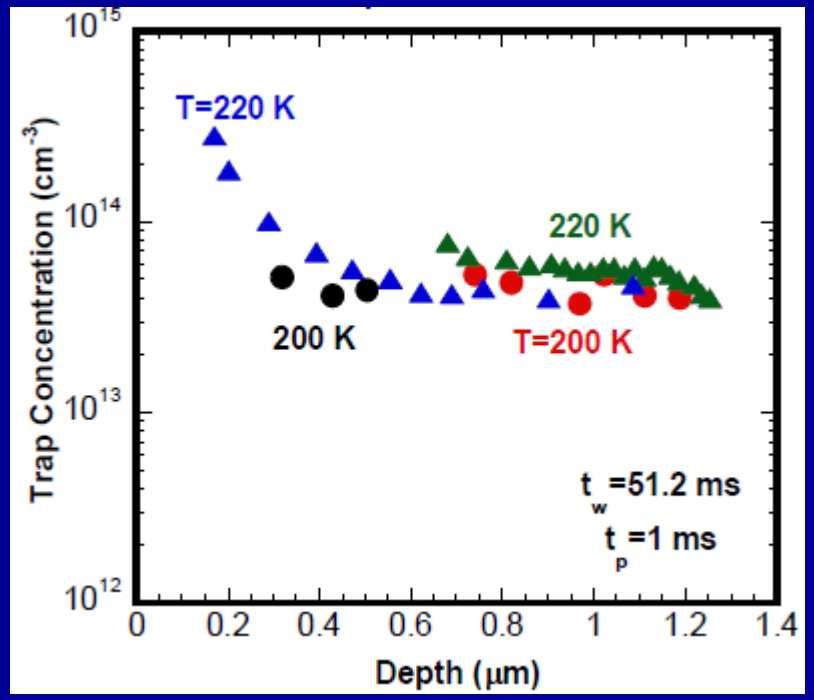
H. Nakashima, et.al, Material Science Forum, vols. 143-147, pp. 761-766, Trans Tech Publications, Switzerland (1994).

Deep Levels in W contaminated p-type Si

DLTS temperature scan



Depth profiles of the W-related traps



Surface contamination dose: 1e12/cm^2

W-related hole traps (E_V+0.409eV) are detected at 210-220K.
The deeper trap concentration decays to 0.5μm depth.

The improvement of the sensitivity of deep level measurements should be required.

E. Simoen, K. Saga, J. Lauwaerta, and H. Vrielincka, ECS Transactions, 64 (11) 219-228 (2014).

Summary

We have extensively reviewed metallic contamination control in CMOS image sensor processing.

- Metallic contamination measurements with high sensitivity and allowing wafer distribution are necessary to improve metallic contamination.
- Ion implantation and backside grinding process bring increased risk of metal penetration.
- Better understanding the behavior of metal impurities penetrating Si is required.
- Surface contamination, minority carrier recombination and deep level measurements with higher detection sensitivity are required.