Blisters formation mechanism during High Dose Implanted Resist Stripping

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Outline

Context

Observation and characterization of blisters

- Blisters characterization (STEM, STEM-EDX and ToF-SIMS)
- Influence of implantation parameters on blisters formation
  - Dopants species (As vs P)
  - Implantation energy and dose

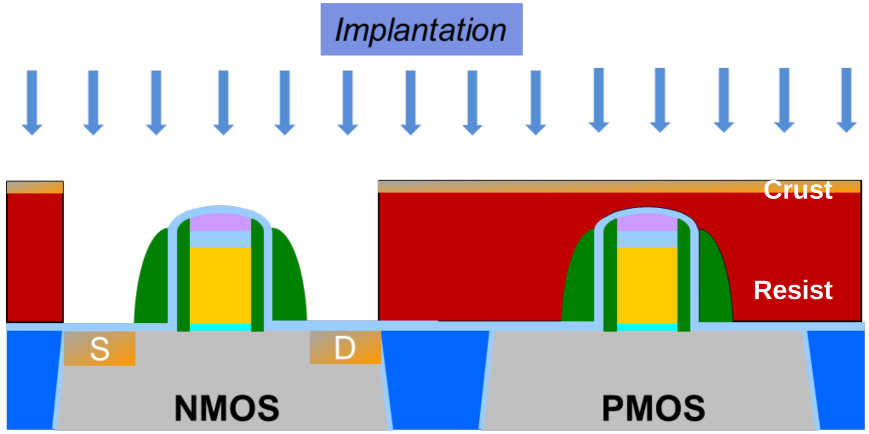
Solutions to avoid blisters formation

- Optimization of dry strip process
- Integration modification

Context

/High Dose Implantation Stripping (HDIS)

Dry strip process after implantation step

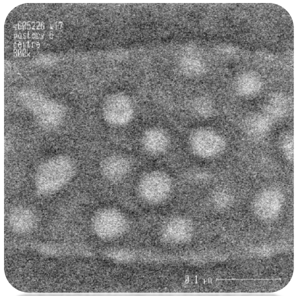


Dry strip challenges

- No remaining residues
- No added defectivity (blisters)
- Minimize substrate loss and oxidation
- No impact on dopant profile

N_2H_2 is the most suitable chemistry for implanted resist stripping in terms of residues removal and low substrate consumption

Limitation → blisters formation after several N_2H_2 stripping processes on implanted area



Example of CMOS integration from Spacer Z to SD formation

- Gate patterning
- SpacerZ
- Si epitaxy
- LDD x5
- Spacer2
- SD x4

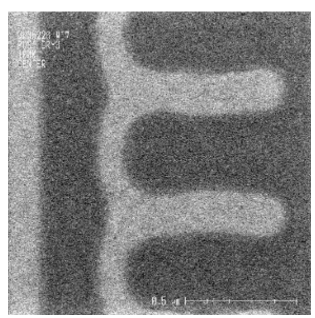
After LDD and NSD → the dry strip chemistry used is forming gas (N2H2 with 3% of H2)

All lithographic rework are based on forming gas

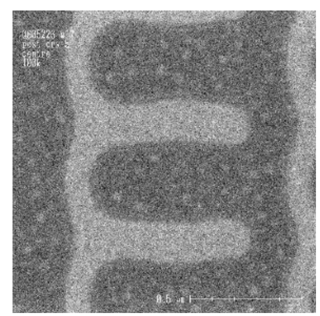
Formation of blisters after several N2H2 processes

Example with P implantation (4keV 1.5E15 at/cm²)

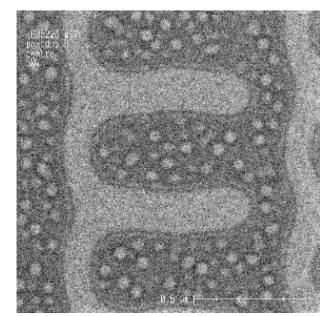
After 4 N_2H_2 dry strip



5 N_2H_2 dry strip



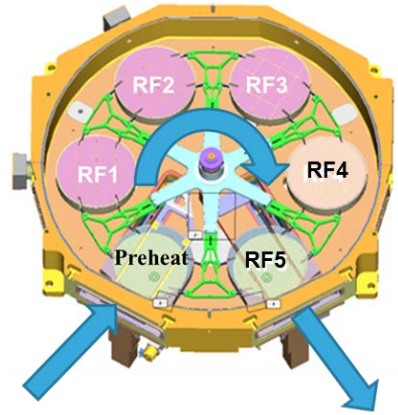
6 N_2H_2 dry strip

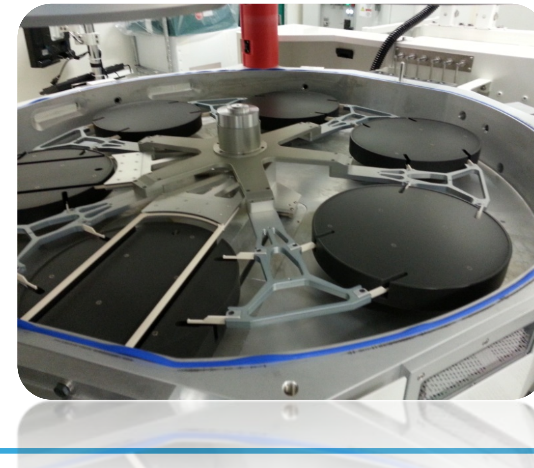


Experimental protocol

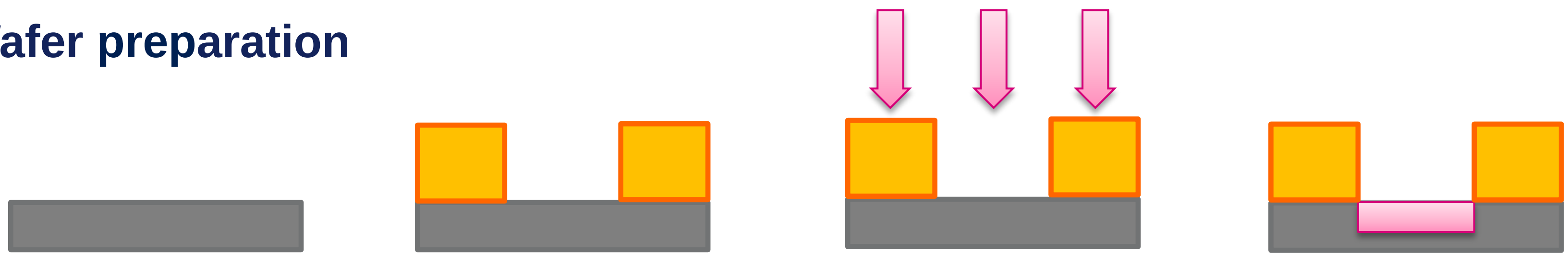
GAMMA tool (LAM Research)

- Downstream plasma
- 6 platens
    - 1 preheat station
    - 5 RF sources
- High temperature (285°C)





Wafer preparation



Bulk Si substrate | NSD lithography | As or P implant | N2/H2 dry strip cumul

Characterizations

In-line : Top view SEM-CD observations

Off-line : Cross section STEM/EDX observation, chemical analysis by ToF-SIMS

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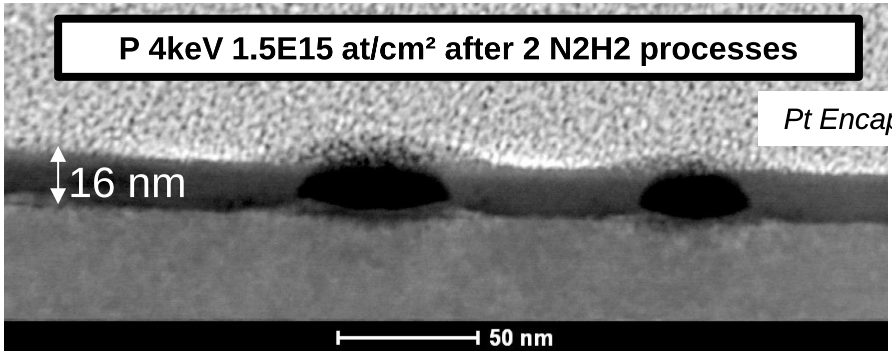
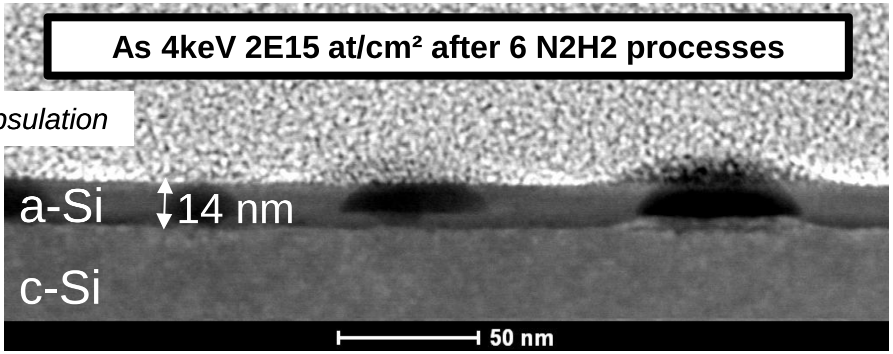
- Integration modification

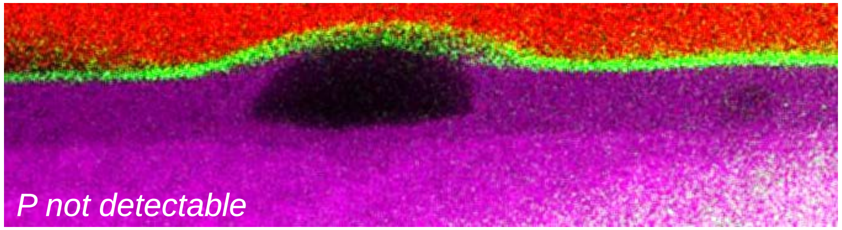
Blisters Characterization
/ STEM and EDX analysis

STEM cross section views

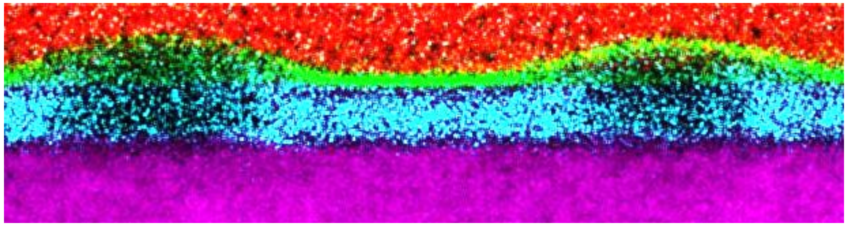




EDX analysis



Pt
O
As
Si

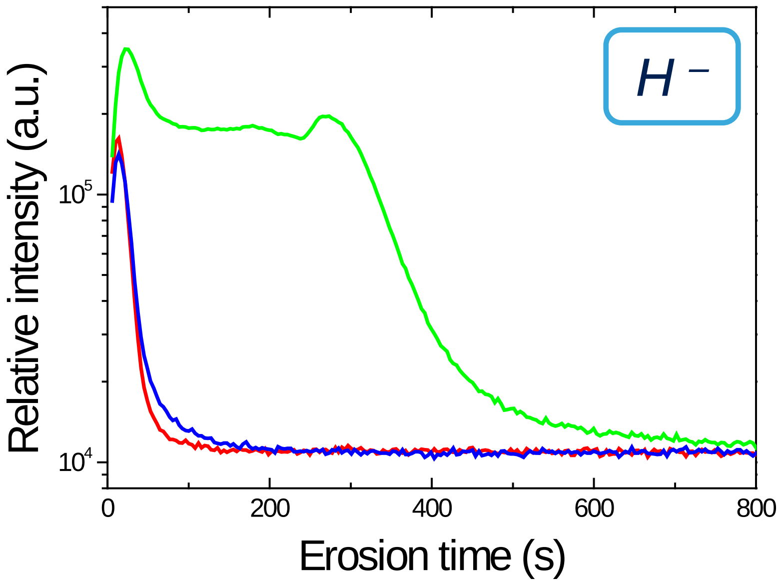


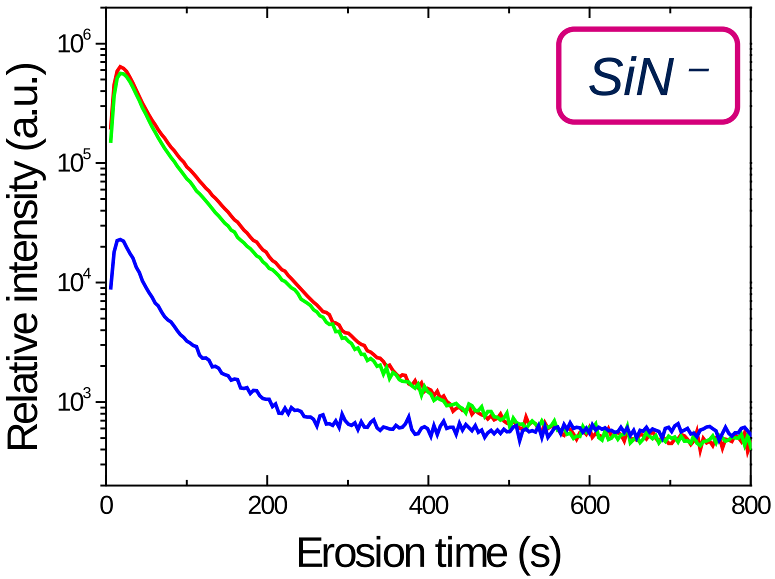
- Bubbles are formed near the Si surface in the implanted area corresponding to amorphous Si
- The surface is lifted by the bubbles
- No dopants are detected on the voids left by the bubbles

no implant 2 N2H2 processes
P 4keV 2N2H2 processes
P 4keV post implantation

Blisters Characterization
/ ToF-SIMS analysis

Evaluation of plasma diffusion in the Si substrate thanks to H^- and SiN^- profiles





- No implantation → Diffusion of N but not H atoms

- P implantation → Similar N diffusion as for the non implanted substrate
  But H diffusion is greatly enhanced and an accumulation is observed

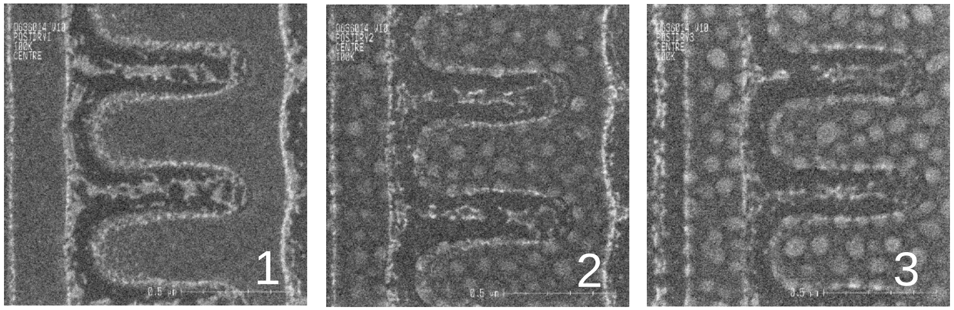
→ **H diffusion and accumulation in the amorphized Si created during the implant are responsible for blister formation**

Blisters Observation

/ Influence of implanted specie (As vs P)

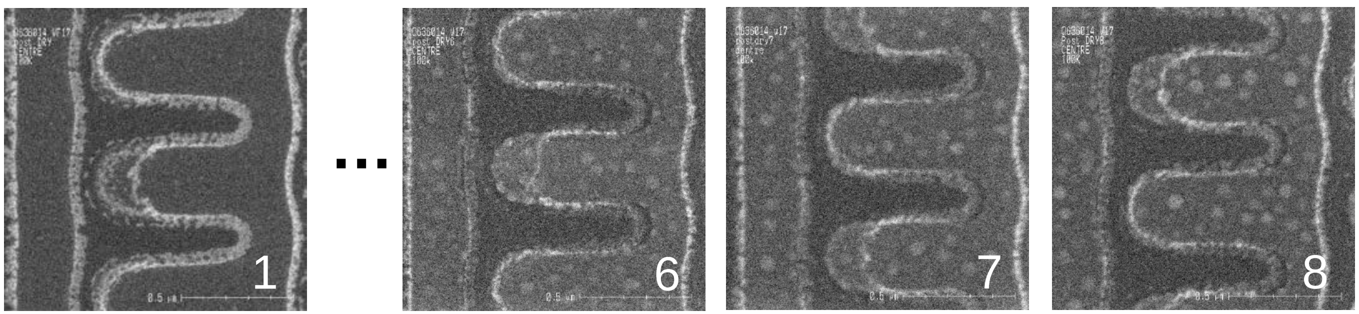
- Photoresist coating and lithography
- Implant P *4keV 1.5ᴱ15 at/cm²*
  or
  Implant As *4keV 2ᴱ15 at/cm²*
- Dry strip N_2H_2

P 4keV



Blisters size 70 - 100nm

As 4keV



50 – 60nm

Influence of dopant specie

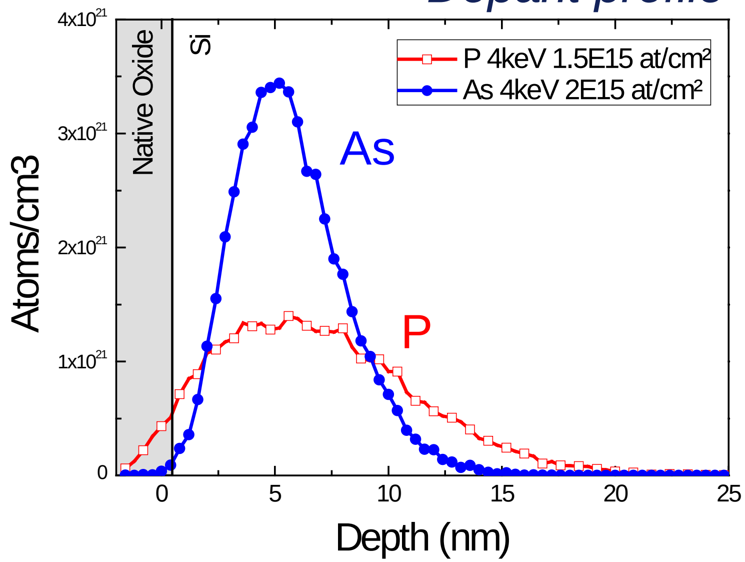
- blisters appear later with As
- larger blisters with P

	Number of dry strip							
	1	2	3	4	5	6	7	8
P 4keV 1.5ᴱ15								
As 4keV 2ᴱ15								

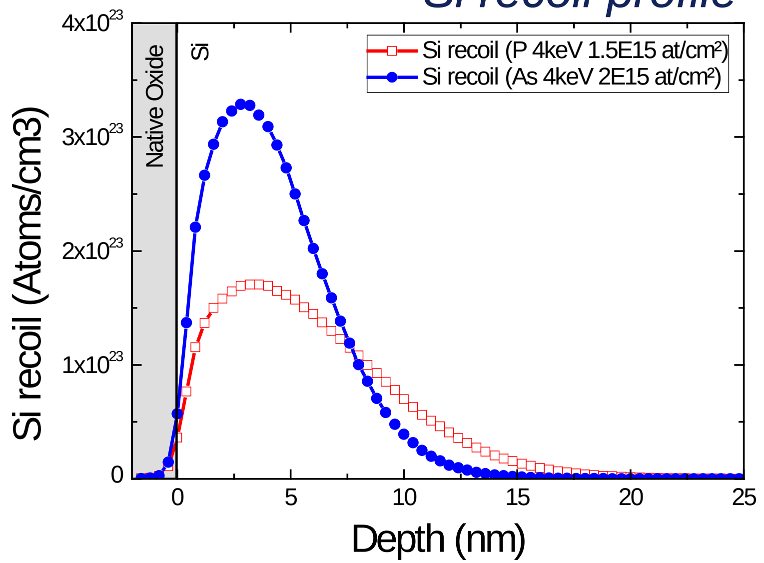
What can explain the difference observed between As and P?

SRIM simulations

Dopant profile



Si recoil profile



Si is considered amorphous when Si recoils > 3.6atoms/cm^3

Amorphized Si thickness

	Simulated (SRIM) (nm)	Measured (STEM) (nm)
P	18	16
As	14	14

- Different dopants profiles but same Rp
- Higher concentration of Si recoils with As → higher amorphization rate
- Thinner amorphized layer for As

Effect of amorphization rate or amorphized layer thickness?

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- Photoresist coating and lithography
- Implant As *3keV*
- Dry strip N_2H_2

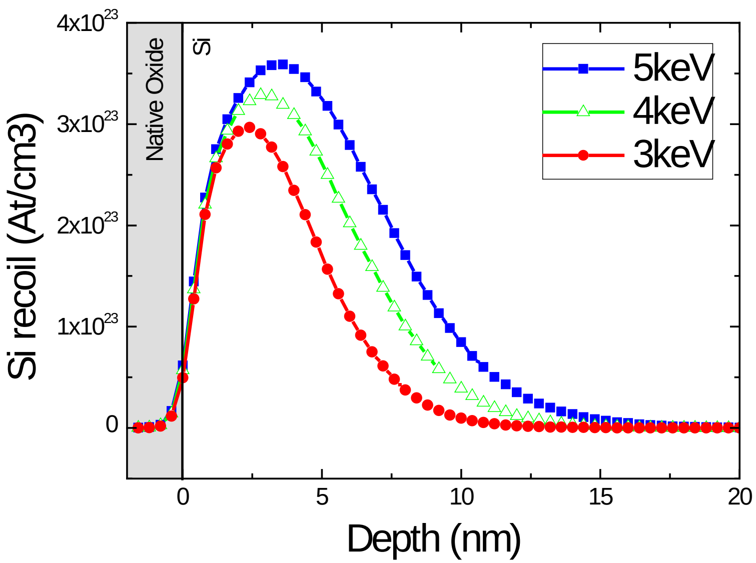
Blisters Post Dry Strip
/ Influence of implantation energy

	Nb of dry strip processes							
	1	2	3	4	5	6	7	8
As 5keV 2E15								
As 4keV 2E15								
As 3keV 2E15								

Amorphized Si thickness (SRIM)

As 5keV	16.4 nm
As 4keV	14 nm
As 3keV	11.4 nm

SRIM simulations



Influence of implantation energy

- Blisters are formed a little earlier with low implantation energies
- At lower energy, the amorphization rate and the amorphized thickness are lower

→ Influence of implantation energy on blisters is limited

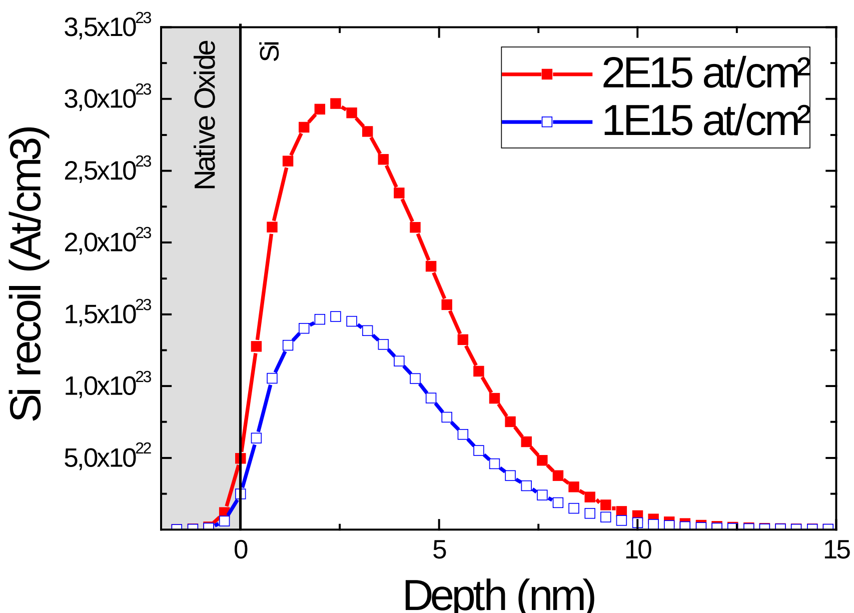
- Photoresist coating and lithography
- Implant As *3keV*
- Dry strip N_2H_2

Blisters Post Dry Strip
/ Influence of implantation dose

	Nb of dry strip processes							
	1	2	3	4	5	6	7	8
As 3keV 2E15								
As 3keV 1E15								

Amorphized Si thickness (SRIM)

As 3keV 2E15	11.4 nm
As 3keV 1E15	10.4 nm



Influence of implantation dose

- Lower dose favors the blisters formation
- At lower dose, the amorphization rate is more than twice lower

→ Influence of amorphization rate on H diffusion and blisters formation

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- Integration modification

- Photoresist coating and lithography
- Implant As *3keV $1^{E}15$ at/cm²*
- Dry strip N_2H_2

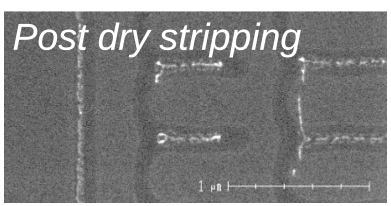
Blisters Post Dry Strip
/ Influence of stripping recipe

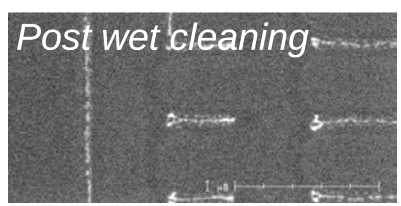
Recipe	Number of dry strip processes				
	1	2	3	4	5
Reference (30s/platen)					
T° ramp + Low P (45s/platen)					
Low P (30s/platen)					

Low process pressure and temperature ramp → the blisters formation is delayed compared to reference recipe

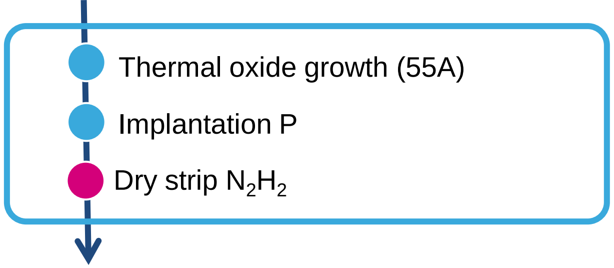
Limitation → remaining residues after dry and wet processes

The stripping is less efficient because of temperature ramping



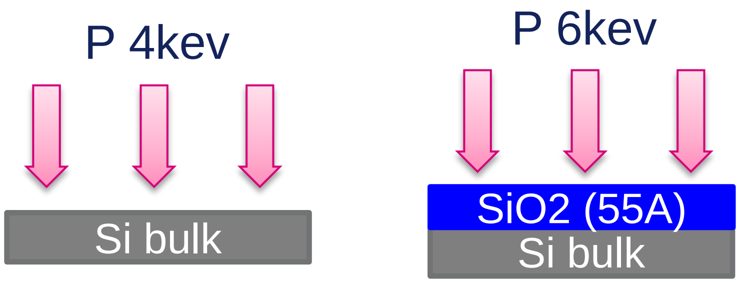


With low process pressure only→ the blisters formation is delayed and no residues remain



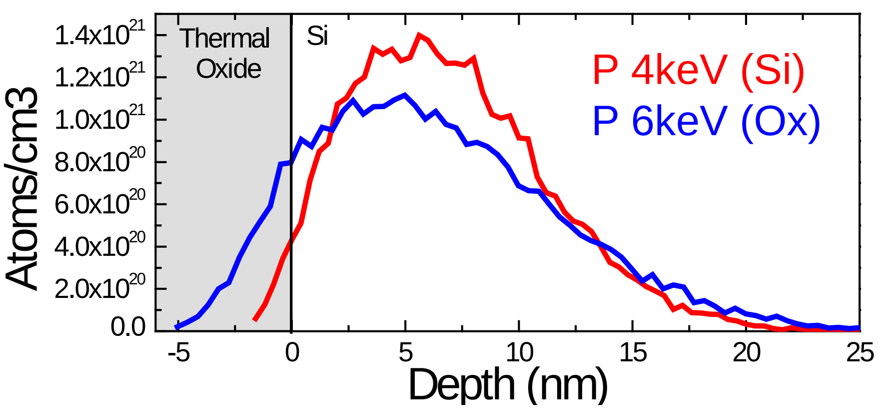
Blisters Post Dry Strip
/ Influence of oxide layer

Modification of the stack→
- Implantation is made through an thermal oxide layer (55A)
- Implantation step is adapted to have similar dopant profiles

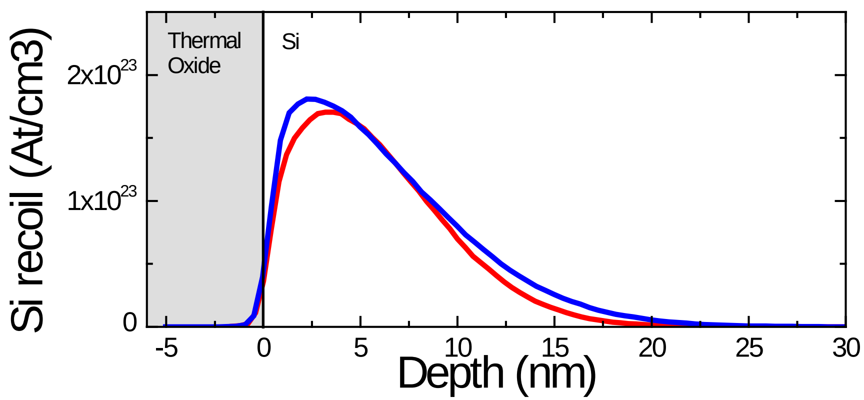


SRIM simulations

Dopant profile



Si recoil profile



- Thermal oxide growth (55A)
- Implantation P 1.5E15 at/cm² 4keV or 6keV
- Dry strip N_2H_2

Blisters Post Dry Strip
/ Influence of oxide layer

		Nb of dry strip				
		1	2	3	4	5
Si	P 4keV					
Oxide	P 6keV					

The oxide layer allows to delay the formation of blisters

→ **What is the effect of the oxide layer?**

		Nb of dry strip				
		1	2	3	4	5
Oxide	P 6keV					
Oxide removed before strip	P 6keV					

Effect on H diffusion

The blisters are formed sooner if the oxide is removed before stripping

The growth of an oxide layer before implantation allows to delay blisters formation by limiting H diffusion in Si substrate

Conclusions

- **Blisters characterization**
  - During N2H2 stripping, H atoms diffuse though the amorphous Si layer and accumulate to form a bubble
  - N2 also diffuses in the substrate but is not responsible for blistering

- **Influence of implantation parameters**
  - Blisters are favored by low implantation dose corresponding to less amorphized Si conditions

- **Solutions against blistering effect**
  - Dry stripping process optimization → low pressure allows to delay blisters formation
  - Integration modification → oxide layer growth before the implantation is beneficial in particular because it decreases H diffusion in the substrate during the plasma process

Thank you for your attention