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# Down to 20nm width photoresist patterns fabricated by using a dry plasma trimming

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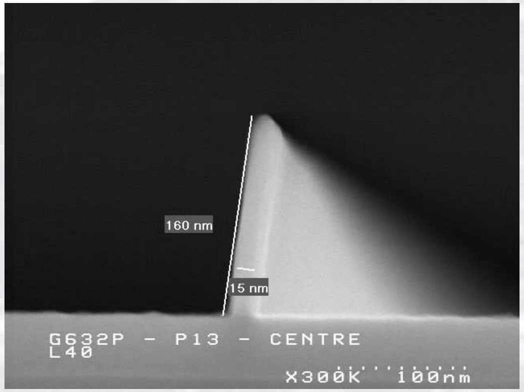


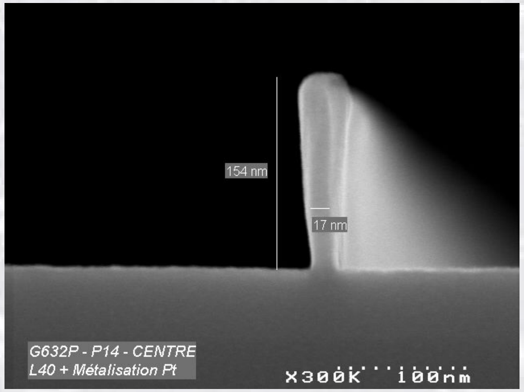


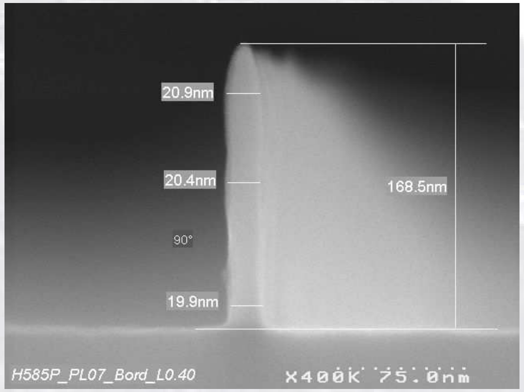


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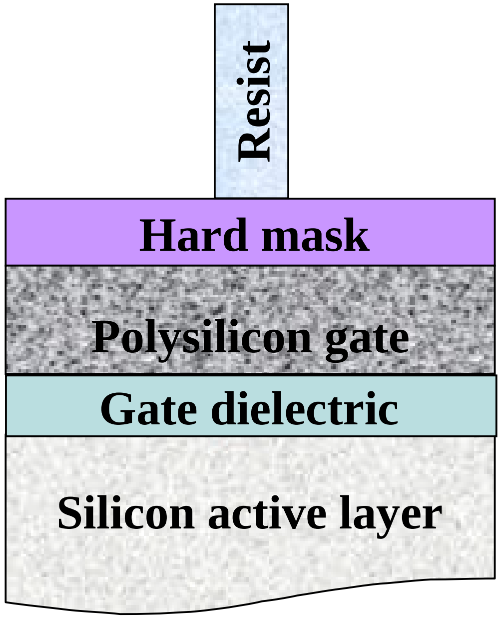
# AGENDA

- **Introduction**
  - Different approaches to reduce the gate width
  - State of the art : resist trimming process
- **Description of the experiment**
- **Results and discussion**
  - Preliminary results
  - $CL_2$-$O_2$ chemistry results
  - Why a hardening step is needed ?
  - The Bi-trimming process
- **Conclusion**

# INTRODUCTION

## Different approaches to reduce the gate width

- Trimming resist
- ~~Hard mask trimming without resist~~
- ~~Hard mask trimming under the resist~~
- Polysilicon trimming
- ~~FOX process~~




- Best dimensions control with dry etching
- Gate Morphology is important

# INTRODUCTION

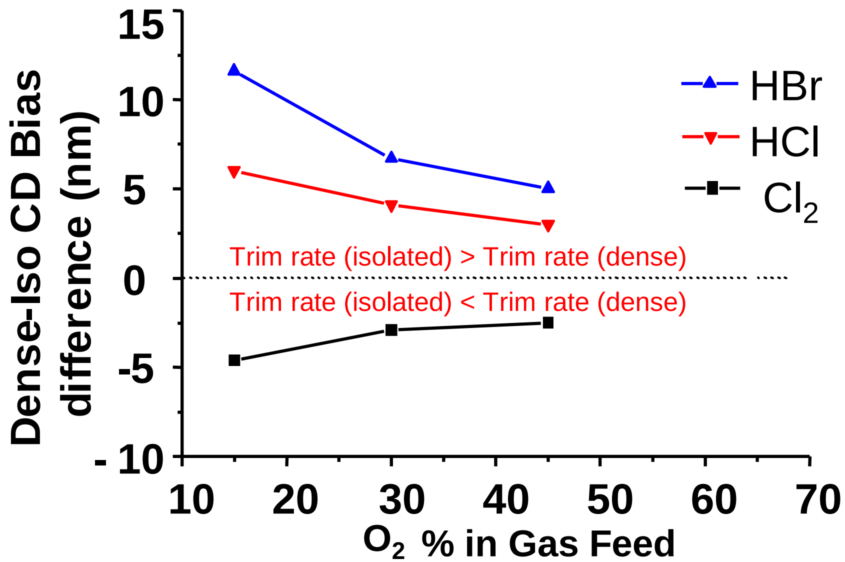
## State of the art : which chemistry should de used ?

- $O_2$ is used to burn the photoresist
- Another gas is necessary to brake the resist burning kinetic
  ($Cl_2$. HBr. $CF_4$. Ar. others ?)

Erwine Pargon thesis (LTM / CNRS)

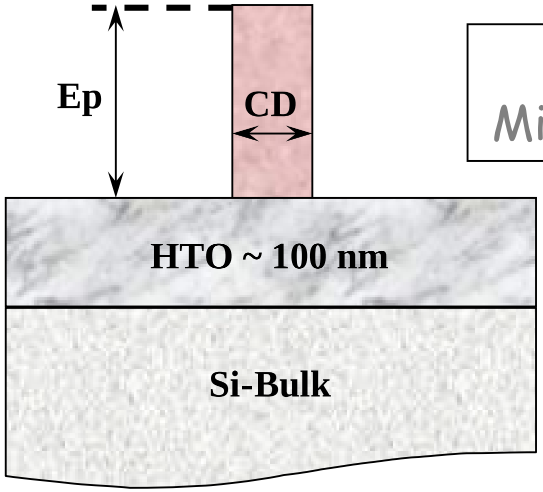
$V(HBr/O_2) > V(Cl_2/O_2)$

$\mu(HBr/O_2) > 0 > \mu(Cl_2/O_2)$




CD Bias = CD $_{\text{after trimming}}$ – CD $_{\text{before trimming}}$

# DESCRIPTION OF THE EXPERIMENT




CD Bias = CD $_{\text{before trimming}}$ - CD $_{\text{after trimming}}$
Microloading = CD Bias $_{\text{isolated line}}$ / CD Bias $_{\text{dense lines}}$

Sumitomo NEB22 E-Beam resist
Thickness before trimming : ~160-200 nm
Gate lithography level
12 E-beam chips checked

CD before and after trimming :
- 40 nm. 50 nm. 65 nm et 75 nm for isolated patterns
- 50 nm for dense lines

# RESULTS AND DISCUSSION

## Preliminary results

- NEB22 resist status :

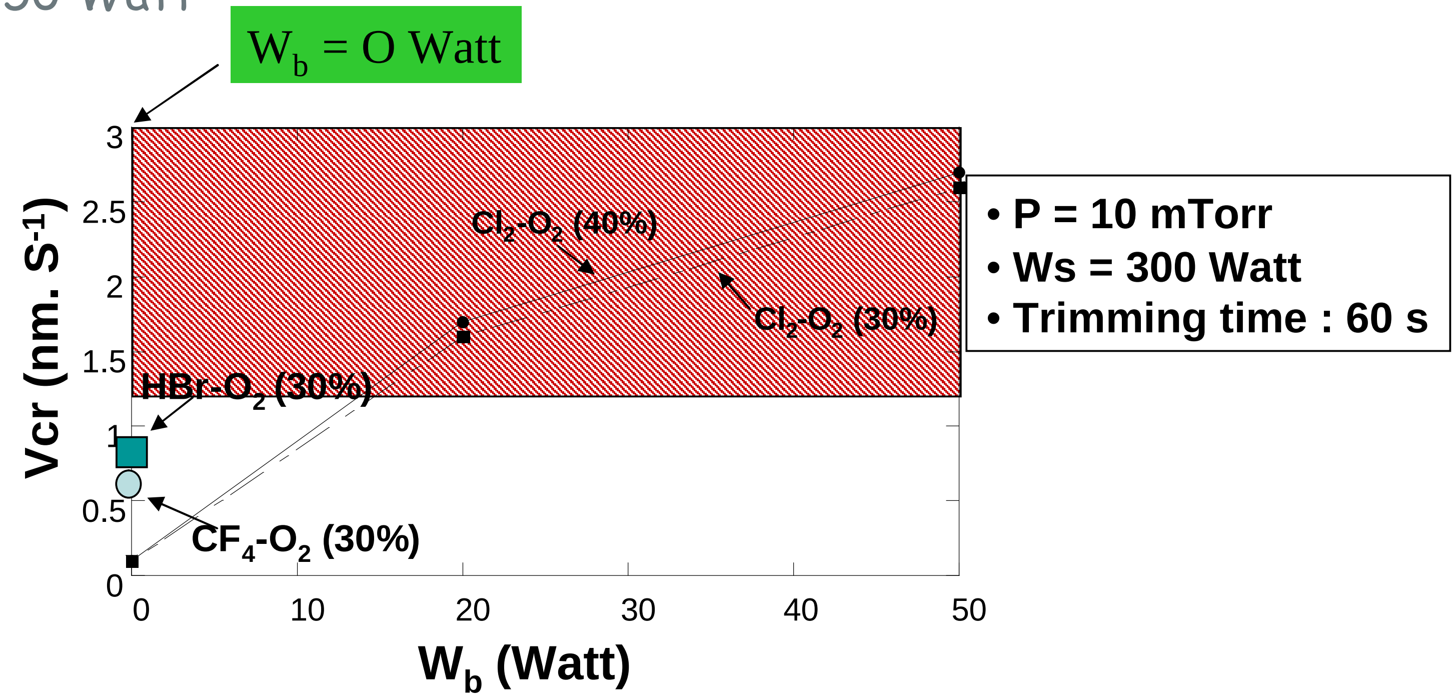
  Hard mask etching (60 nm) : $Ep_{NEB22}$ must be up to 60 nm

  Active layer etching : $Ep_{NEB22}$ must be up to 120 nm

  ☞ **$Ep_{NEB22\ trimmed} \leq 80$ nm => Vcr ≤ 1.3 $nm.s^{-1}$ (for trimming time of 60 s)**

- Equipment status :

  $W_b$=0 or $W_b \geq 50$ Watt

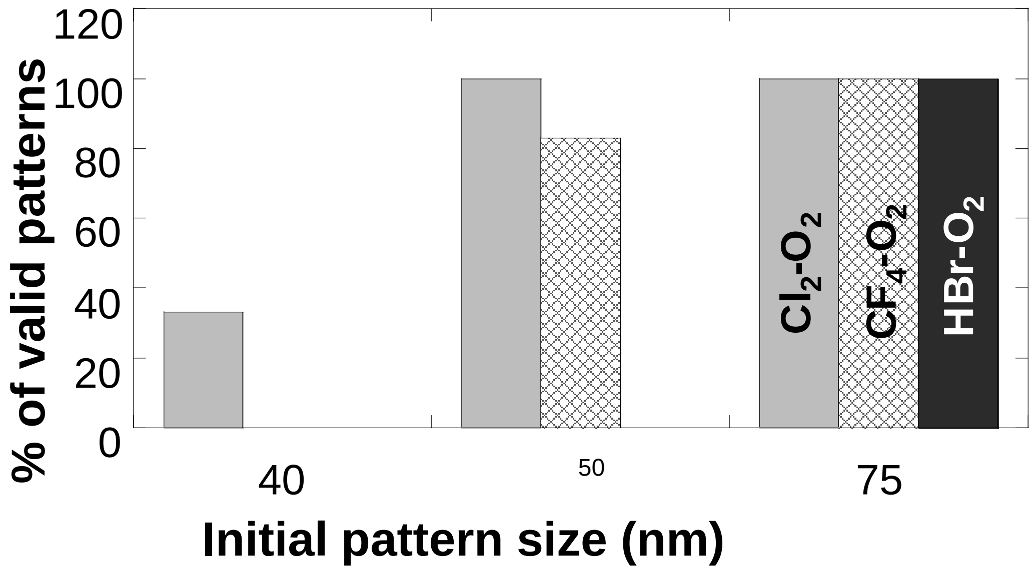


# RESULTS AND DISCUSSION

## Preliminary results

- Different gases for $O_2$ dilution : $Cl_2$ or $CF_4$ or HBr

| Chemistry | Process time (s) | Vertical etch rate (nm.s-1) | Trim etch rate (nm.s-1) | Microloading |
|---|---|---|---|---|
| $Cl_2$-$O_2$ | 120 | 0.08 | 0.25 | 1.1 |
| $CF_4$-$O_2$ | 30 | 0.6 | 0.8 | 1.25 |
| HBr-$O_2$ | 20 | 0.9 | 1.2 | 1.5 |




- P = 10 mTorr
- Ws = 300 Watt
- Q = 200 sccm
- $CD_{after\ trim}$ : 44 nm -> 18-22 nm

# RESULTS AND DISCUSSION

## Preliminary results

- $W_b$ = 0 Watt :
  - ➢ Resist consumption is lower : **<< 1.3 nm. $S^{-1}$**
- The best chemistry is $Cl_2$-$O_2$ :
  - ➢ Resist consumption is the lowest : **only 0.2 nm. $S^{-1}$**
  - ➢ Best throughput after trimming

**"The most slowly you trim. the highest throughput you have"**

# RESULTS AND DISCUSSION

## $CL_2$-$O_2$ chemistry results : $O_2$ concentration impact

Fixed parameters :

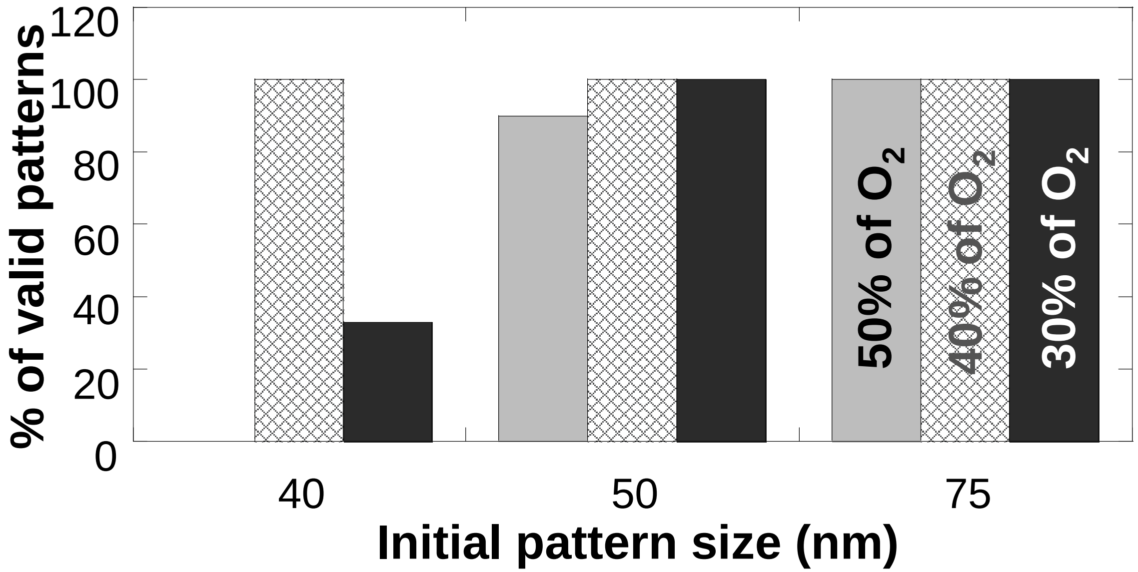
- P = 10 mTorr
- Ws = 300 Watt
- Wb = 0 Watt
- Q = 200 sccm
- $t_{trim}$ = 60 s

| % of $O_2$ | Vertical etch rate (nm.s-1) | Trim etch rate (nm.s-1) | Microloading |
|---|---|---|---|
| 50 | 0.185 | 0.35 | 1.3 |
| 40 | 0.1 | 0.3 | 1.1 |
| 30 | 0.8 | 0.15 | 0.85 |

☞ 30% d'$O_2$ < "microloading = 1"< 40 % d'$O_2$

# RESULTS AND DISCUSSION

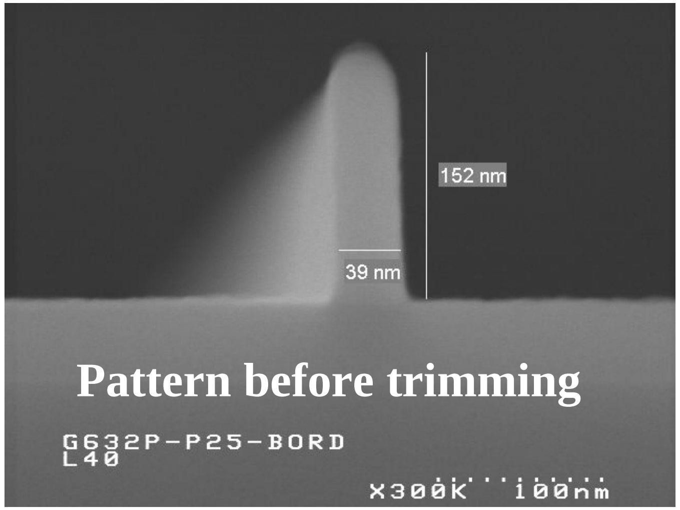
## $CL_2$-$O_2$ chemistry results : $O_2$ concentration impact

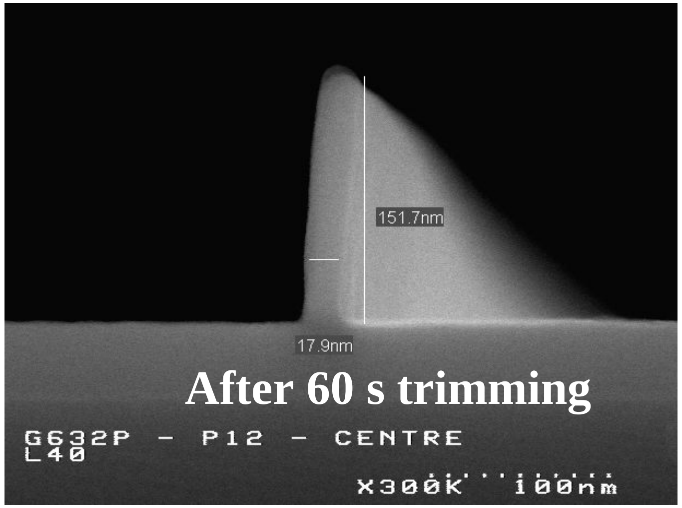


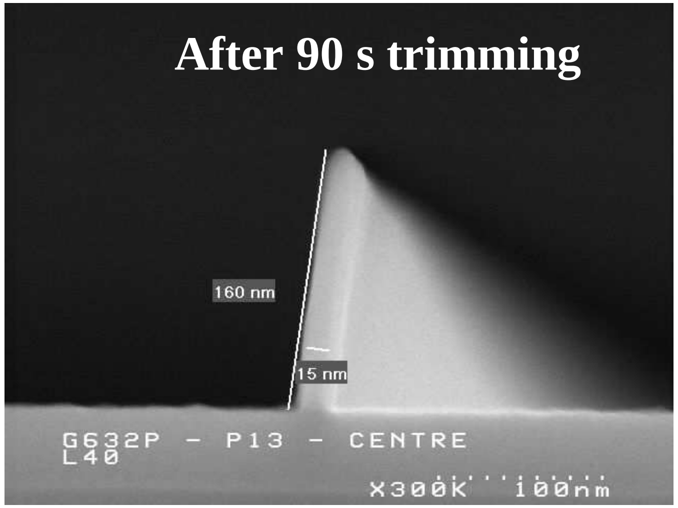

- % of valid patterns decrease with $O_2$
  "The most slowly you trim. the highest throughput you have"
- 40% of $O_2$ seems to be the best compromise between the yield and the microloading

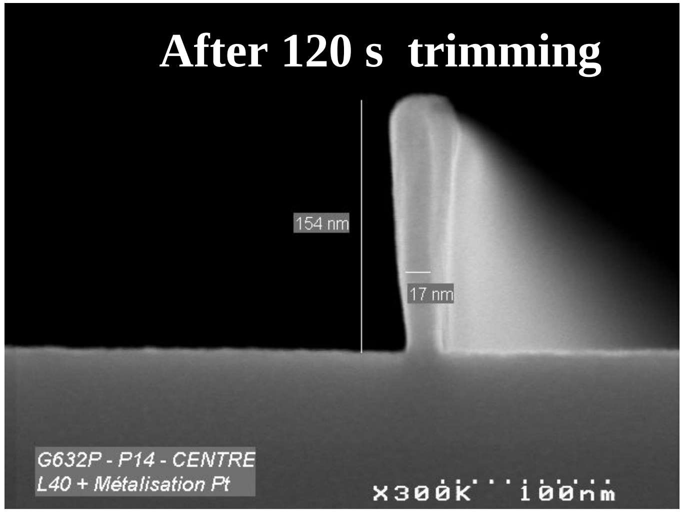
# RESULTS AND DISCUSSION

## $Cl_2$-$O_2$ chemistry results : trimming time impact



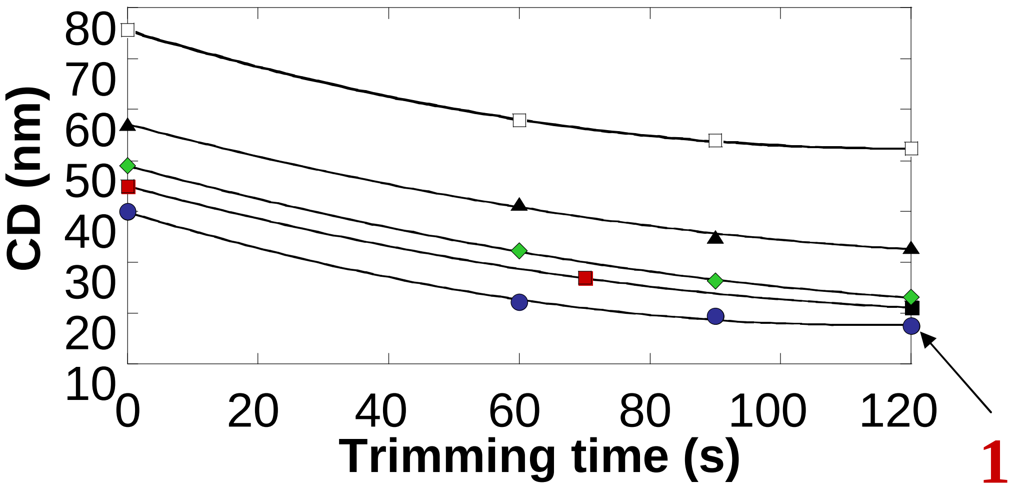



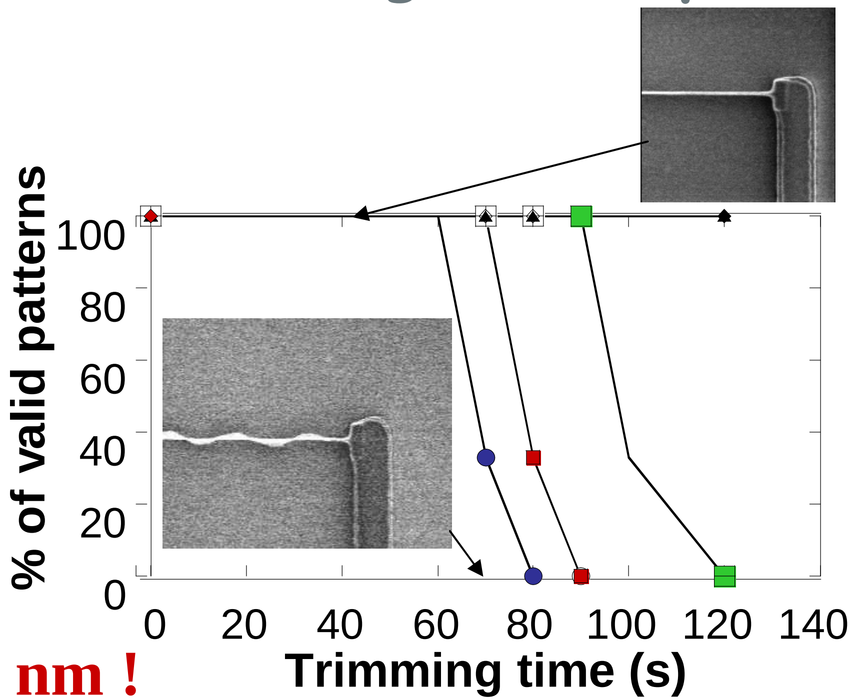



# RESULTS AND DISCUSSION

## $CL_2$-$O_2$ (40%) chemistry results : trimming time impact




**18 nm !**




Limit width after trimming for a yield of 100% : 22-23 nm

- **40-45 nm : 60 s process**
- **50-55 nm : 90 s process**

# RESULTS AND DISCUSSION

## $CL_2$-$O_2$ (40%) chemistry statistical results

Gate width reduction :

- Goal : reduce isolated line width from 40 nm to 20 nm
- 12 E-Beam chips characterized on 20 processed wafers
- Trimming without hardening step during 60 s
- CD values before /after trimming :
  - 43nm (40) / 24 nm
  - 48 nm (50) / 32 nm
  - 72 nm (75) / 56 nm

Active zone reduction :

- Goal : reduce isolated and dense line widths from 50 nm to 30 nm
- 5 E-Beam chips characterized on 19 processed wafers
- Trimming without hardening step during 90 s
- CD values before /after trimming :
  - 45nm (iso-50) / 24 nm
  - 48 nm (résH-50) / 29 nm
  - 48 nm (résV-50) / 29 nm

# RESULTS AND DISCUSSION

## Why a hardening step is needed ?

- To reach CD lower than 20 nm with a high output
- Why patterns fall down ?
  - ➢ The trimming process
  - ➢ The chamber pumping and the wafer dechuck after process
  - ➢ Wafer moving
  - ➢ Scanning Electron Microscopy observations
  - ➢ Hard mask and active zone etching
  - ➢ Sample cleavage for SEM observations

- Which solution can be used ?
  - ➢ A resist hardening as post-trimming step

# RESULTS AND DISCUSSION

## Why a hardening step is needed ?

- Description of the hardening step
  - Ws = 1500 Watt
  - Wb = 0 Watt
  - P = 5 mTorr
  - Q = 150 sccm
  - Process time = 60 s

- Results
  - 46 nm : 60 s → 90 s process
  - 56 nm : 90 s → 120 s process

- Drawbacks
  - Impossible to increase the trimming time without decreasing the yield
  - Limit after trimming and hardening always at 22-23 nm

➢ ***A second trimming step is needed***

# RESULTS AND DISCUSSION

## The Bi-trimming process

| Parameters | 1irst trimming | 1irst hardening | 2nd trimming | 2nd hardening |
|---|---|---|---|---|
| Time (s) | 90 | 60 | 40 | 60 |
| Wb (W) | 0 | 0 | 0 | 0 |
| Ws (W) | 300 | 1500 | 300 | 1500 |
| Chemistry | $Cl_2$-$O_2$ | HBr | $Cl_2$-$O_2$ | HBr |
| Pressure (mTorr) | 10 | 5 | 10 | 5 |
| % of $O_2$ | 40 | | 40 | |

# RESULTS AND DISCUSSION

## The Bi-trimming process

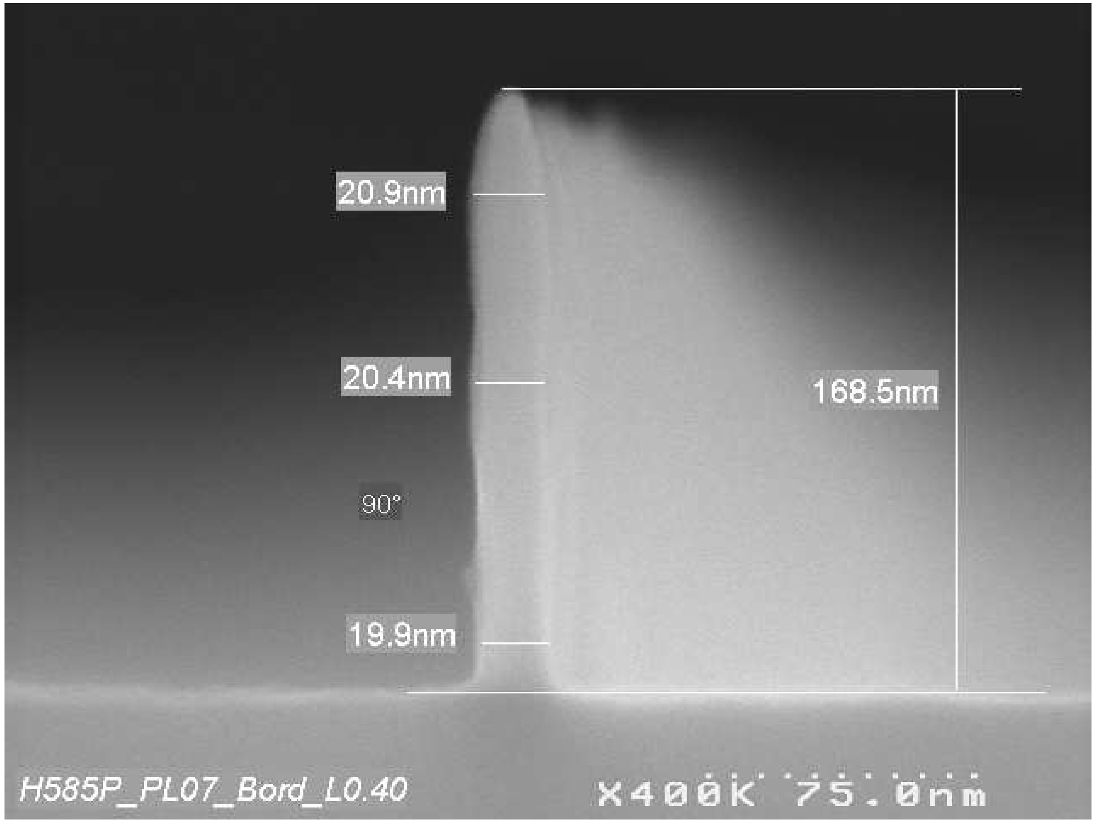
- SEM CD : 6 patterns on 12 E-Beam chips / 5 wafers

| | CD before trimming (nm) | | | CD after trimming (nm) | | |
|---|---|---|---|---|---|---|
| **Pattern size** | **40 nm** | **50 nm** | **75 nm** | **40 nm** | **50 nm** | **75 nm** |
| H585-P06 | 46 | 58.7 | 79.4 | 19.3 | 30.2 | 51.1 |
| H585-P07 | 45.7 | 58.7 | 78.1 | 18.5 | 28.8 | 48.6 |
| H585-P08 | 46.2 | 57.6 | 77.2 | 21.8 | 32 | 51.9 |
| H585-P09 | 46.6 | 58.8 | 79.2 | 22.2 | 32.8 | 53.7 |
| H585-P10 | 44.6 | 56.5 | 76.5 | 20 | 30.1 | 50.2 |
| **Mean** | 45.8 | 51.7 | 78.1 | 20.4 | 30.8 | 51.1 |

☞ $\Delta CD$ ~ 26.5 nm with $\Delta CD_{trim2}$ ~ 5-6 nm

# RESULTS AND DISCUSSION

## The Bi-trimming process



# CONCLUSION

- $W_b$ = 0 Watt and $Cl_2$-$O_2$ chemistry
  - Resist consumption is lowest **~ 0.2 nm. $S^{-1}$ << 1.3 nm. $S^{-1}$**
  - Best throughput after trimming and microloading between isolated and dense lines near 1
- $Cl_2$-$O_2$ process
  - 40% of $O_2$ seems to be the best compromise between a high yield and a microloading
    near 1
  - It's possible to have microlading close to 1
  - Limitations : it's difficult to trim under 22-23 nm without resist hardening
  - A process with two trimming steps is necessary to reach resist width lower than 20 nm
- The bi-trimming $Cl_2$-$O_2$
  - Only possibility of going down below 20 nm with good outputs
  - Microloading to be characterized
  - Good resist behavior during etching of a hard mask of 100 nm

# Thank you for your attention

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