Application of plasma parameter measurement by SEERS on oxide etch process development for new DRAM shrink generations in AMAT eMax chamber

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Acknowledgement

- The results presented in this paper were supported partially:
  - by the EFRE fund of the European Community
  - and by funding of the State Saxony of the Federal Republic of Germany, project SENSOR.
- The authors are responsible for the content of the paper.

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Outline

- Description of process and experiment
- Process development
  - Characterisation of plasma parameters by variation of B-Field, pressure and RF-power
  - Verification of plasma parameter impact on product wafers
  - Investigation of conditioning and warm up procedure
- Benefit of plasma parameter measurement during process development
- Summary

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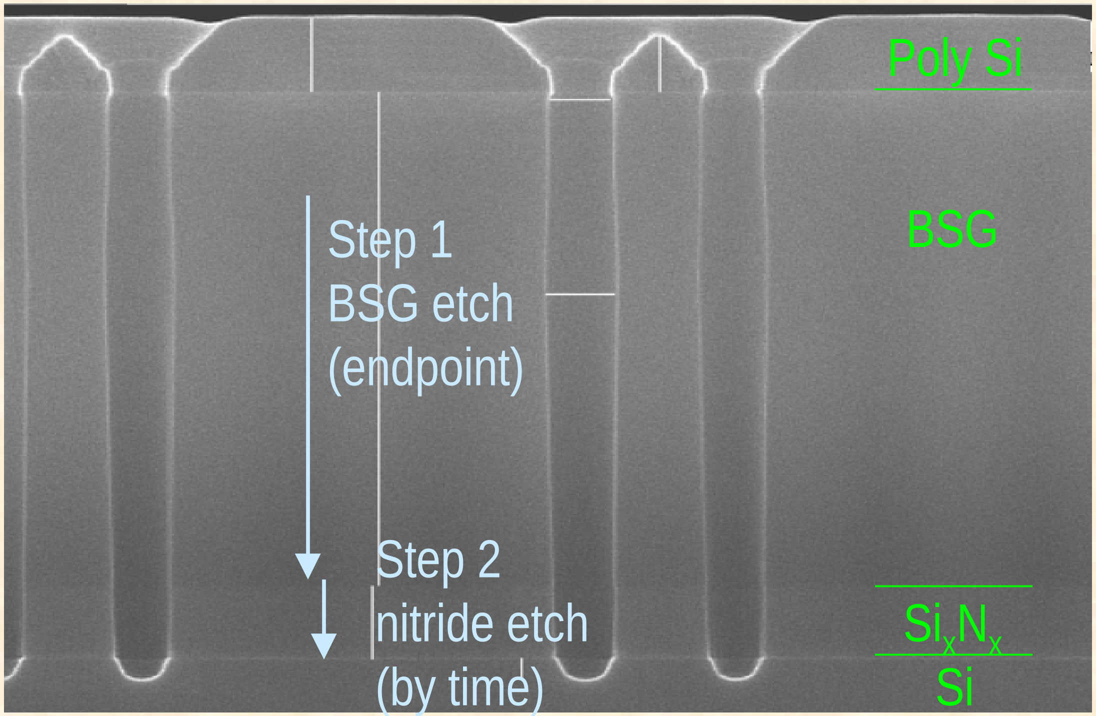
Typical oxide etch SEM picture



- Oxide etch in two steps:
  - First BSG is etched using a Poly-Si mask and an optical endpoint system
  - Second Nitride is etched for a fixed time
- The result is a high aspect ratio trench

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Aim of experiments

- Characterisation of process window by use of plasma parameters
  - Assessment of optimisation potential for existing process
- Enhancement of conditioning procedures
- Investigation of warm up effects

Experimental set up of characterisation experiment

- Before experiment:
  Chamber- conditioning and warm up with 3 conditioning wafers
- Design of experiment::
  - Power variation using nine wafers (unpatterned Si-Wafer) in three steps
  - Pressure variation in three steps for every power setting
  - B- field variation in 6 steps for every wafer

			Step							
Wafer	Power	Pressure	1	2	3	4	5	6	7	
1	1400 W	20 mTorr	Stab	40	60	80	100	120		H [Gauss]
2		40 mTorr	Stab	20	40	60	80	100	120	
3		60 mTorr	Stab	20	40	60	80	100	120	
4	1800 W	20 mTorr	Stab	40	60	80	100	120		H [Gauss]
5		40 mTorr	Stab	20	40	60	80	100	120	
6		60 mTorr	Stab	20	40	60	80	100	120	
7	2000 W	20 mTorr	Stab	40	60	80	100	120		H [Gauss]
8		40 mTorr	Stab	20	40	60	80	100	120	
9		60 mTorr	Stab	20	40	60	80	100	120	

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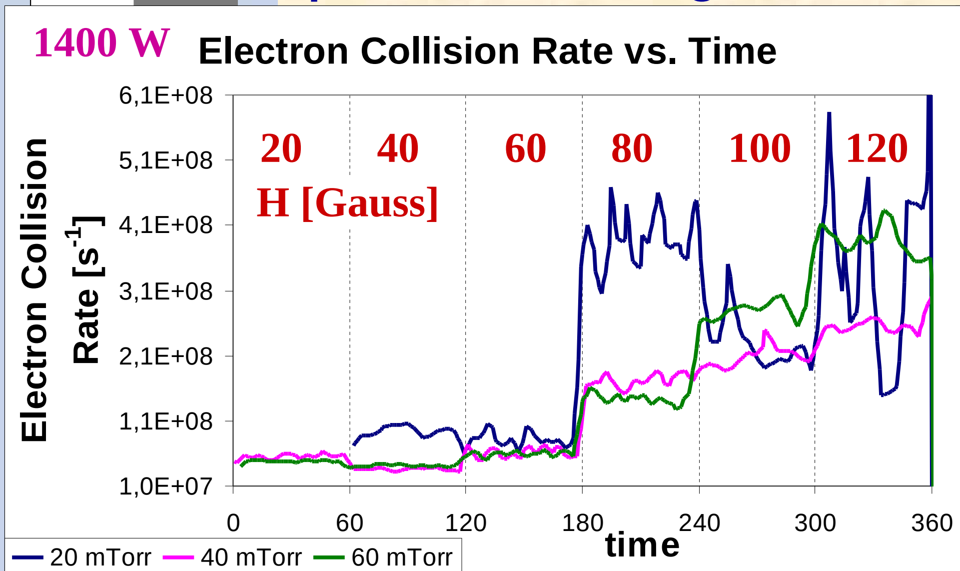
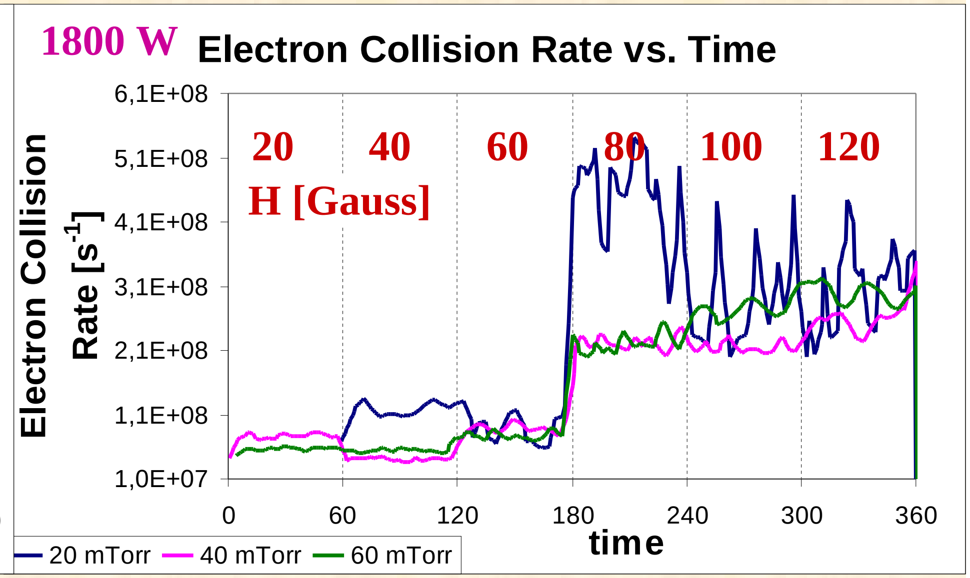
Electron collision rate vs. process time for three power settings





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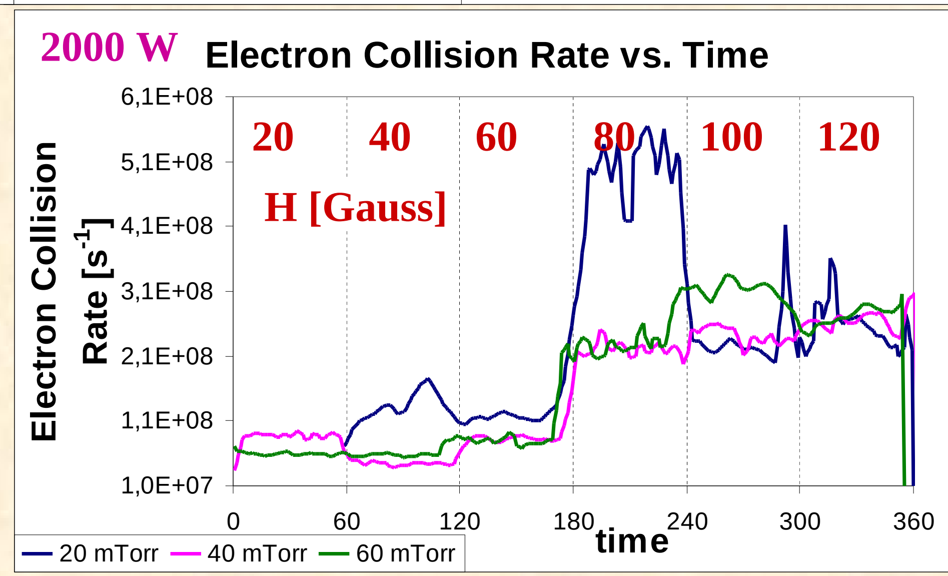
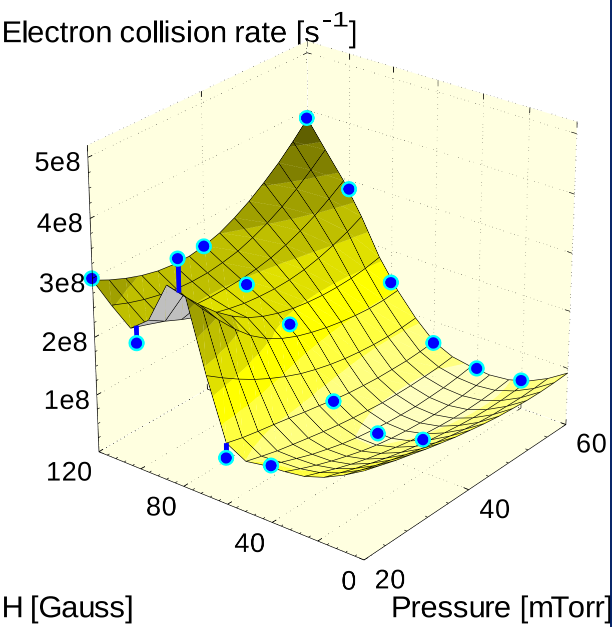
- At 20 mTorr electron collision rate indicates very unstable process at medium and higher B-Field
  - è pressure too low

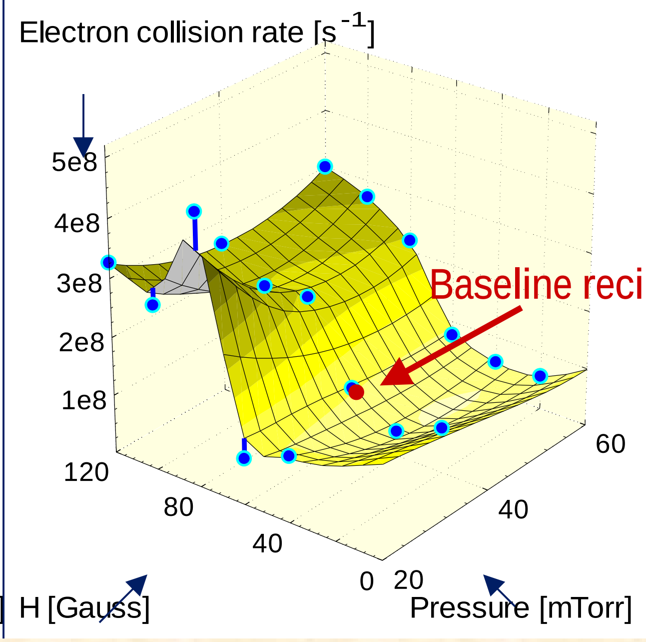


Median electron collision rate vs. B-field and pressure for RF power 1400, 1800 and 2000 W

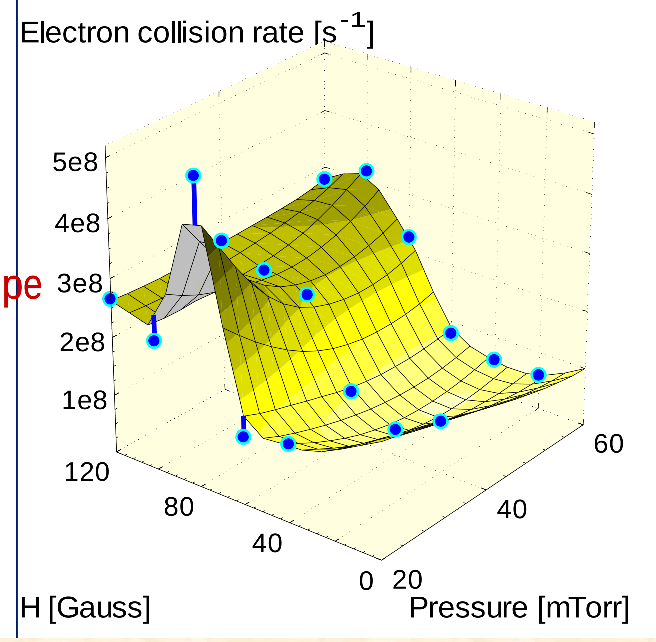
Electron collision rate vs. B-Field and Pressure (1400W)



Electron collision rate vs. B-Field and Pressure (1800W)



Electron collision rate vs. B-Field and Pressure (2000W)



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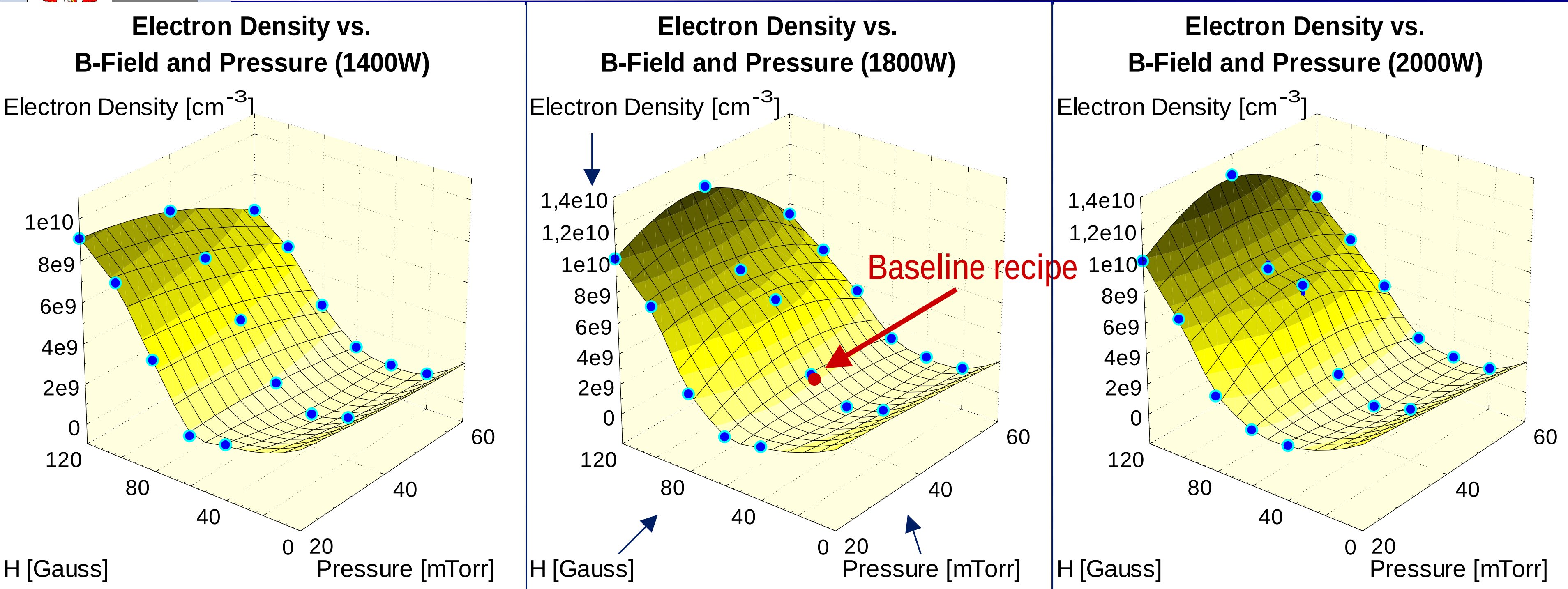
- 20mTorr processes were very unstable and should not be considered
- Baseline recipe has a comparatively low electron collision rate è potential for optimisation: going up to 80 Gauss at 40 mTorr could result in an increasing number of reactive species in the plasma

Median Electron Density vs. B-Field and Pressure for RF Power 1400, 1800 and 2000 W



- There is a small dependence of electron density on pressure and a big one on magnetic field strength
- Higher electron density should lead to higher ion density and therefore could cause an increasing ion bombardment on the wafer surface

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Repeatability test with unpatterned Si-wafers: Charts of electron density and collision rate

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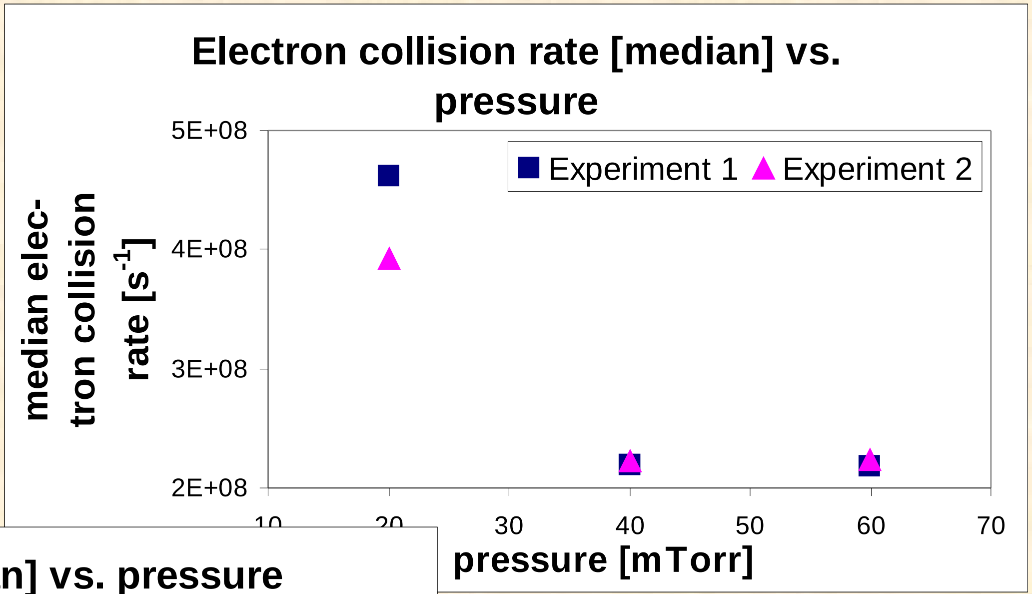

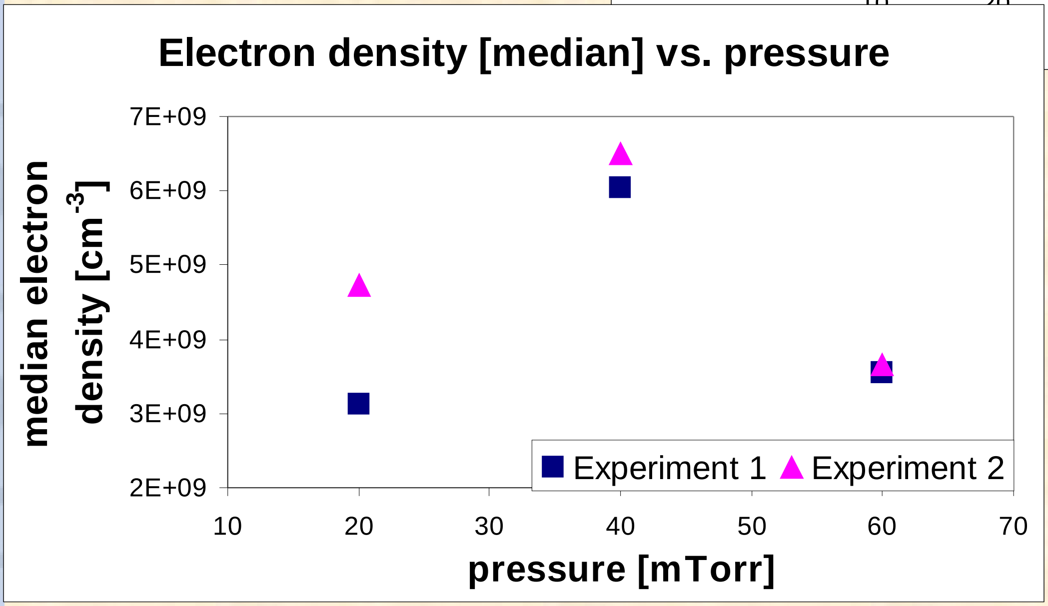

- There is a good reproducibility of experimental results
- Discussion on next page

Repeatability test with unpatterned Si-wafers: explanation

- Results of electron collision rate and electron density are reproducible for 40 and 60 mTorr
- Median electron density and electron collision rate for 20 mTorr process different between experiments because of unstable process

è Plasma parameters allow a reliable prediction of chamber conditions

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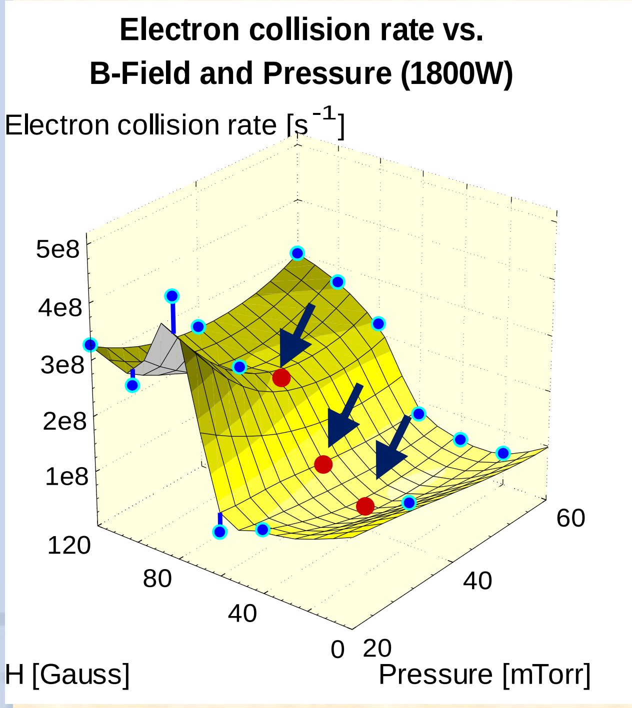
Experiments on product wafers



- Baseline process was found to be at an unfavourable point: There was a strong rise in electron collision rate when changing B-field to slightly higher values
  è process susceptible to fluctuations in process parameters ?
- Impact of 3 B- field settings on geometric properties of patterned product wafers was investigated
- Magnetic Field was set to 40, 60 and 80 Gauss in BSG step at 1800W and 40 mTorr
- There was no magnetic field in the nitride step

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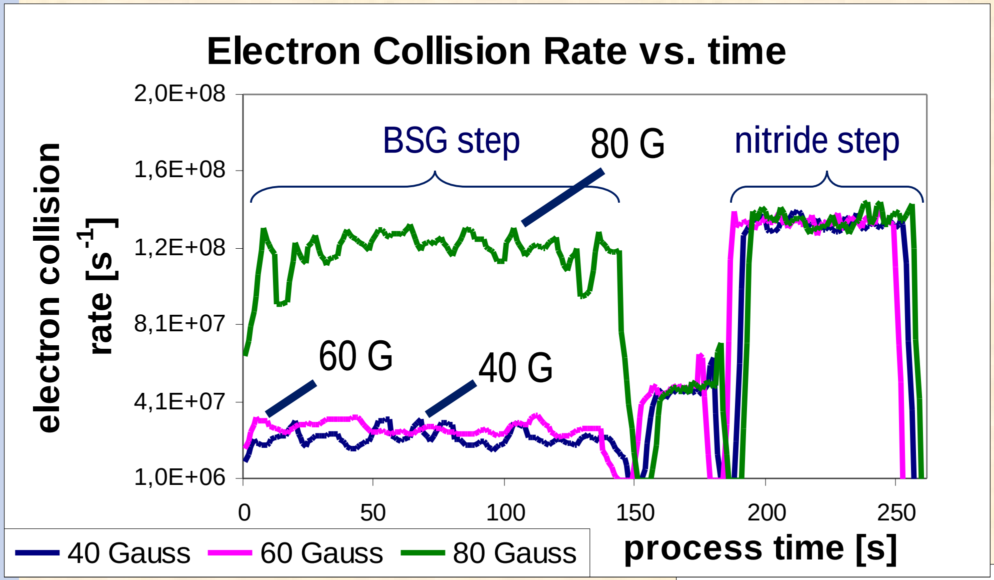
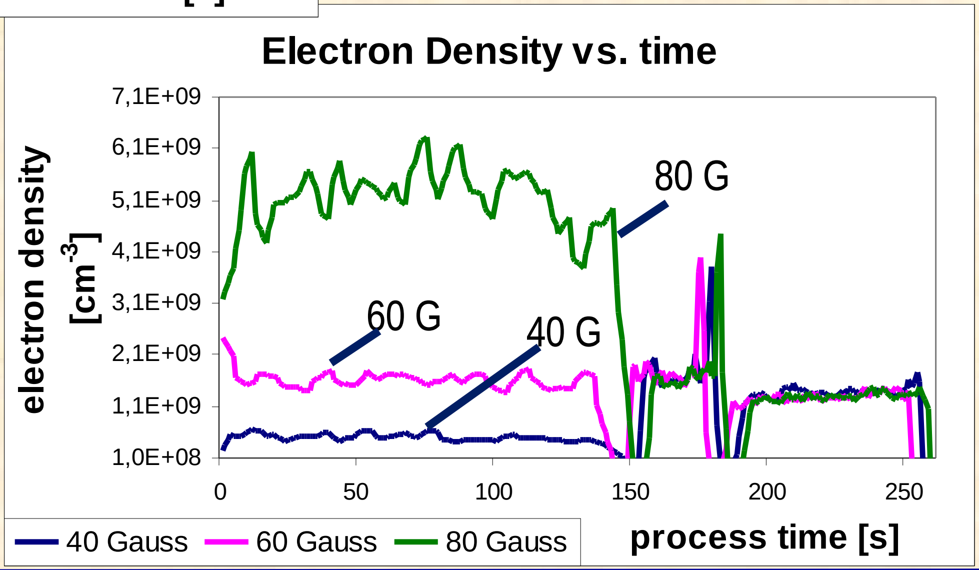
Tests on patterned product wafers: Electron density and El. collision rate for B-Field Variation



- 80 Gauss process produces different results in electron collision rate

- Electron density increases with rising magnetic field, as observed in previous experiments on test wafers



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Tests on patterned product wafers: Explanation

- Electron collision rate and electron density measured during B-field variation on product wafers behave similar to measurements on unpatterned Si-wafers
- Again high electron collision rate and electron density in BSG step for an 80 Gauss setting is observed
- In nitride step, where no magnetic field is present, all values are at the same level

SEM cross-sections of patterned wafers - etched with different B- field settings

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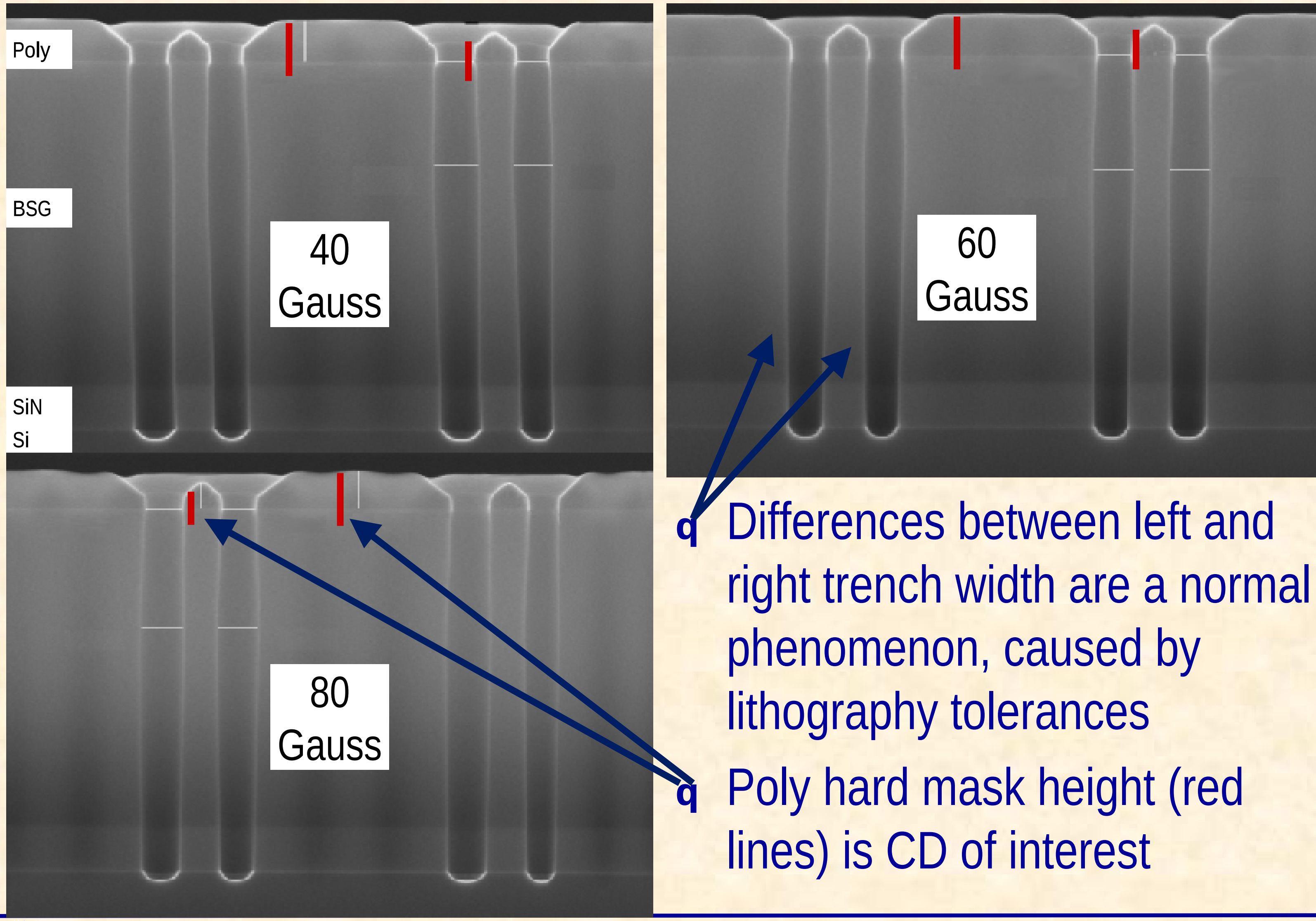
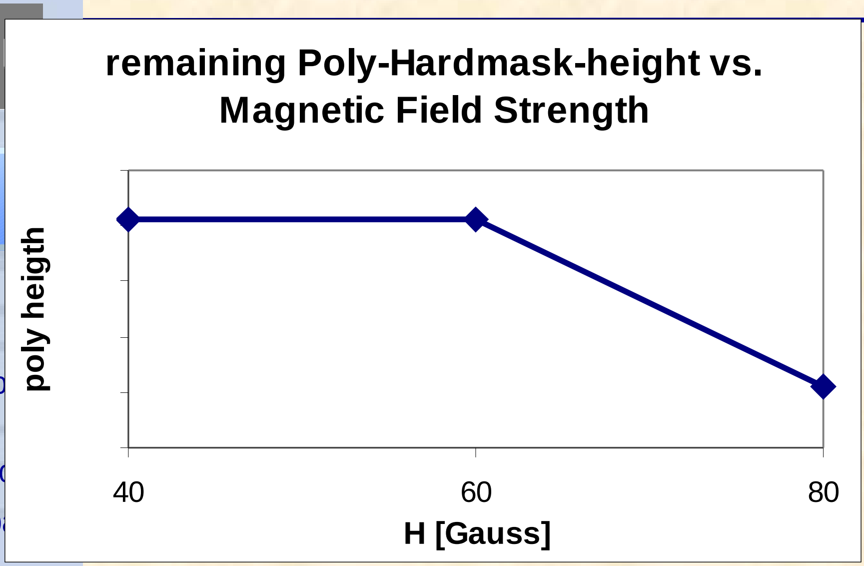
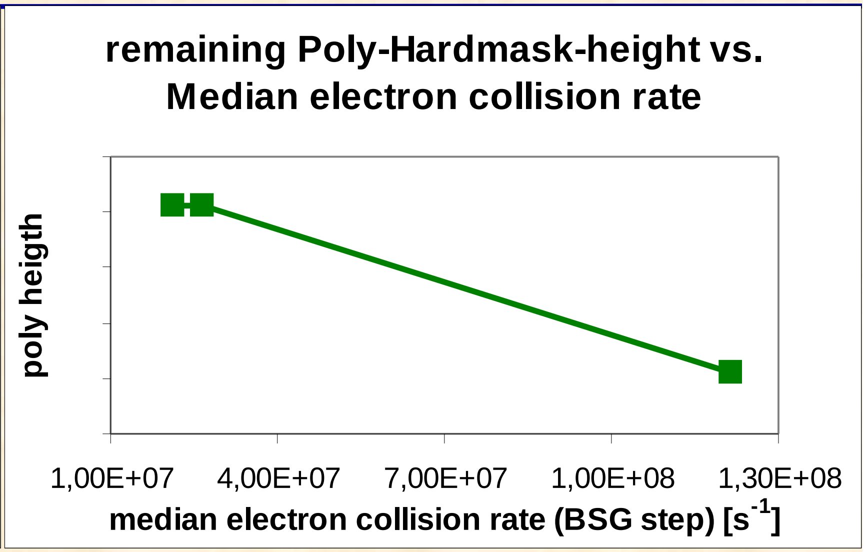


- Differences between left and right trench width are a normal phenomenon, caused by lithography tolerances
- Poly hard mask height (red lines) is CD of interest

Discussion of REM cross sections





- Etch rates on test wafers were nearly equal for 60 and 80 Gauss, but selectivity of BSG to other layers was about 10% higher at 60 Gauss è Poly hard mask height is smaller for 80 Gauss
- This correlates to plasma parameters: Electron collision rate correlates to poly mask height
- This is not critical, because mask is thick enough to resist etching and all other dimensions are nearly equal for different B- fields

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Investigation of Conditioning and Warm up - Part 1

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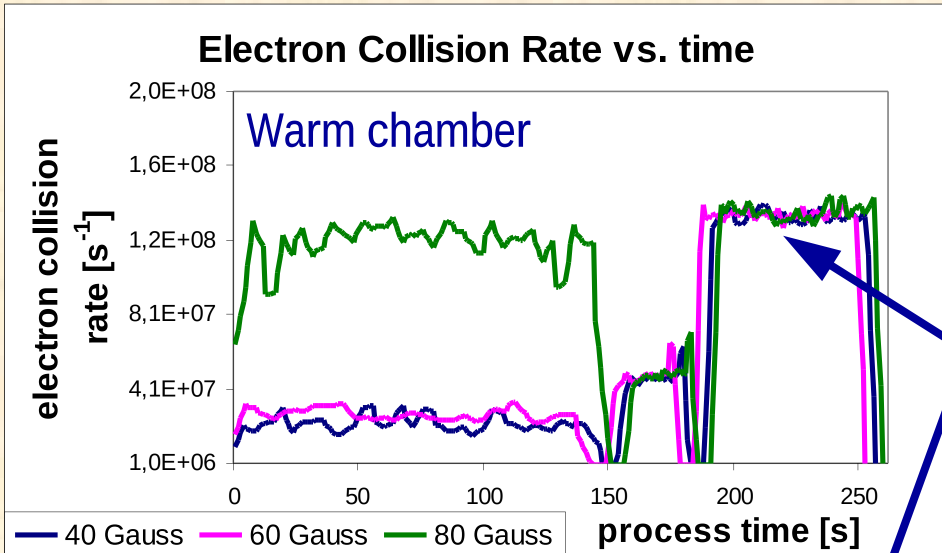
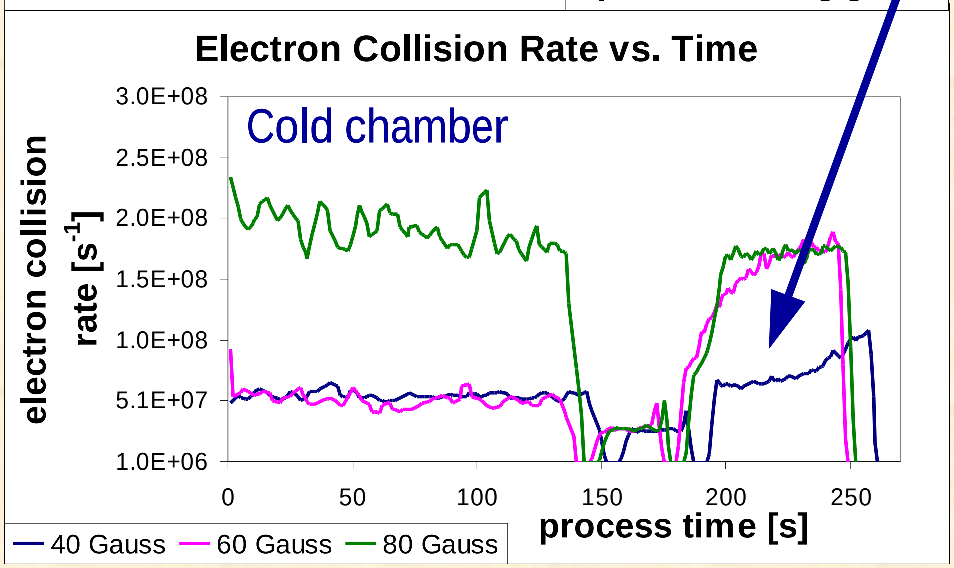
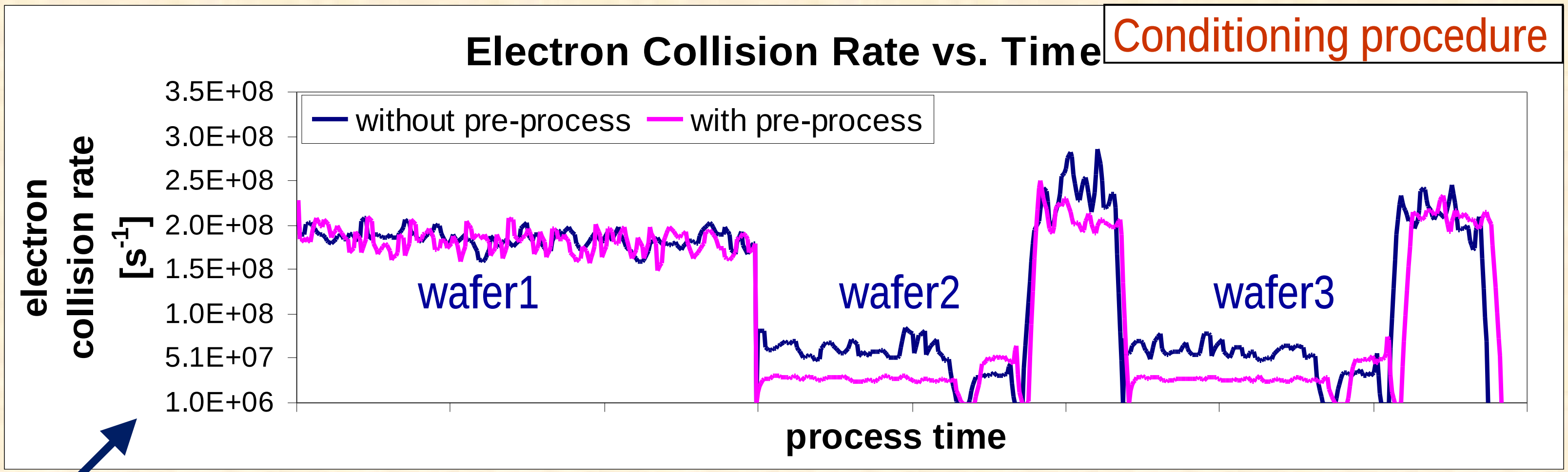




- Experiment in upper chart started with warm plasma chamber
- experiment in lower chart started with cold chamber
- there are clear differences in (temperature sensitive) nitride step
- it needs two additional wafers until conditions are stable again

Investigation of Conditioning and Warm up - Part 2

- *Warm up* is insufficient: 3 conditioning wafers are not enough to heat up chamber - at least 4 are necessary (nitride etch is very temperature sensitive !)



- *Conditioning procedure* with 3 conditioning wafers is sufficient - no first wafer effect observed for conditioning wafers and first (40 Gauss) product wafer
- First experiment (upper graph, previous page): other processes before experiment
- No impact of pre- process on electron collision rate for following experimental wafers

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Benefit of plasma parameter measurement

- Plasma parameters were used to characterise oxide etch process by parameter variation and showed potential for process development and optimisation.
- They indicated temperature and conditioning effects → they are a powerful tool to verify conditioning and warm up procedures with minimal effort in real time.
- It was shown that plasma parameters give reproducible results and can be used for stability control and failure detection.
- Additional measurement techniques are necessary for investigation of chemical reactions, e.g., optical emission spectroscopy.
- Correlation to selectivity was shown → plasma parameters can be used to optimise processes

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Summary

- An oxide etch process has been characterised using plasma parameters electron collision rate and electron density by variation of pressure, power and B- field.
- Unstable processes have been found for a pressure of 20mTorr - this pressure should be avoided for wafer processing.
- Experiments on product wafers showed a correlation of plasma parameters to remaining Poly-Si thickness and selectivity.
- 60 Gauss process is recommended, because its selectivity is highest.
- Conditioning procedure with two conditioning wafers is sufficient to eliminate pre-process influence on products.
- Warm up procedure with two conditioning wafers is insufficient - strong temperature influence has been found.