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Arcing prevention by dry clean optimization at Shallow Trench Isolation (STI) Etch in AMAT MxP by use of plasma parameters

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Outline

- Introduction –
  Shallow Trench Isolation (STI) etch process
- Arcing at STI etch in AMAT MxP chamber
- SEERS measurement technique
- Development of a new dry clean using plasma parameters for real time process monitoring
  - Basic experiments (not shown in this publication)
  - Optimization of clean step
  - Optimization of conditioning step
  - Optimization of clean-/conditioning time
  - Long term evaluation
- Summary

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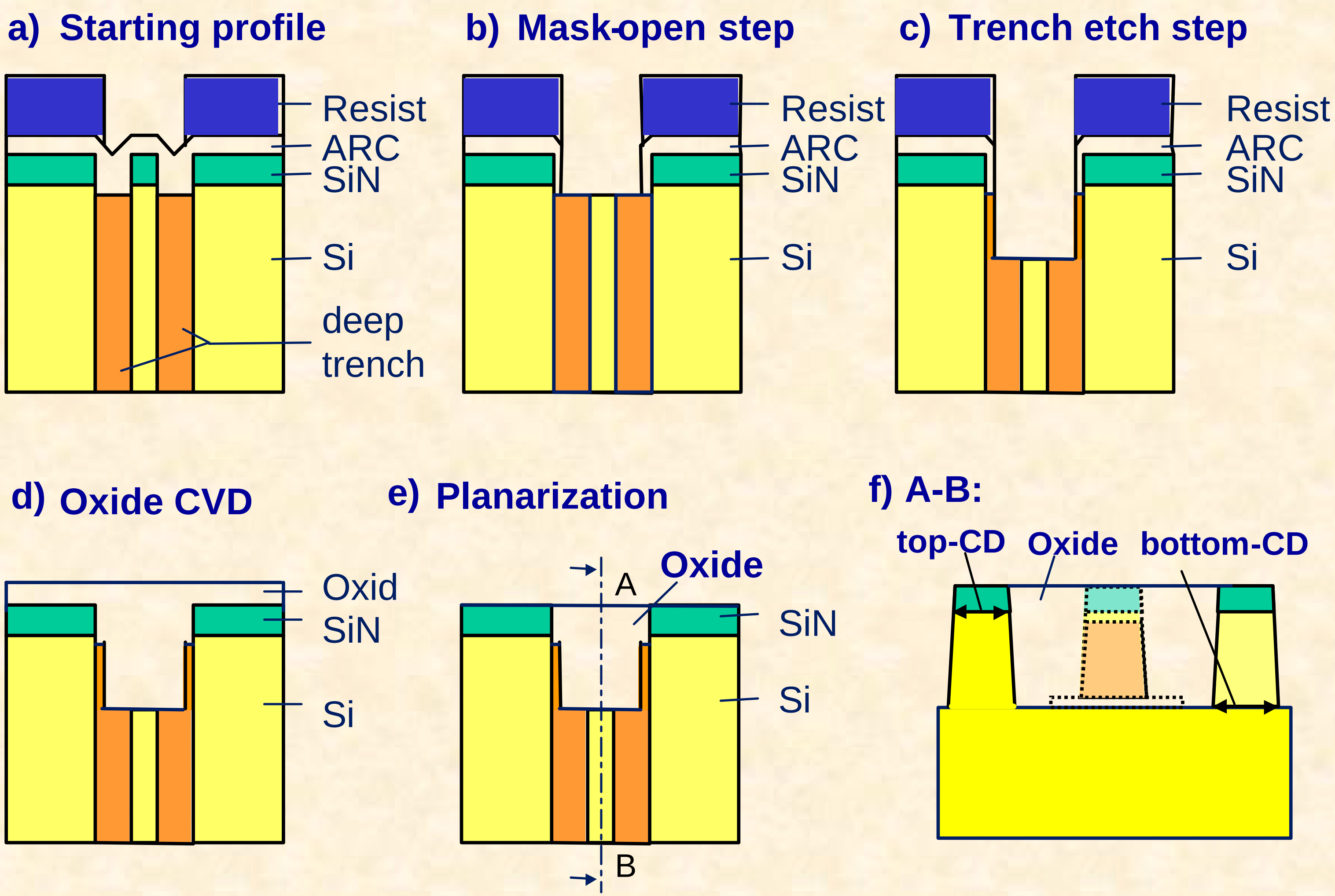
STI etch process - Overview



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Arcing – what´s that ?

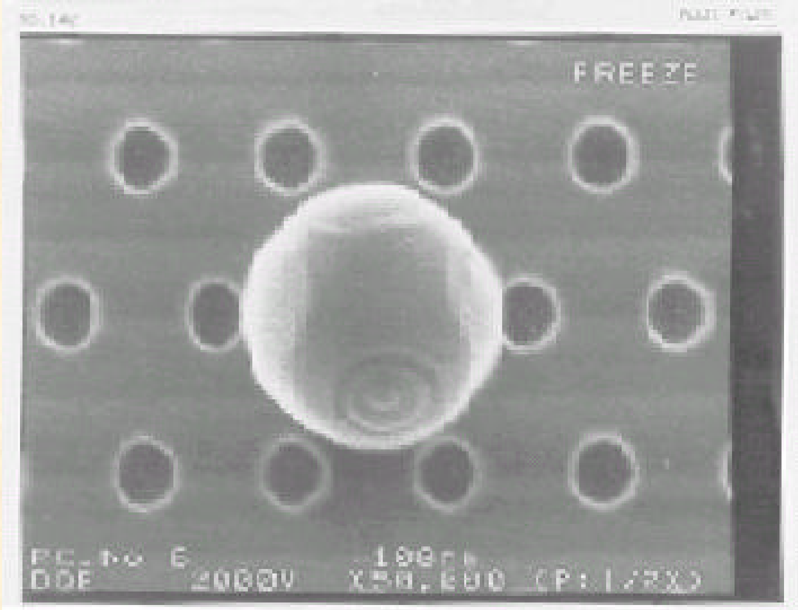

Fig.: Arcing generated Aluminum particle on wafer surface

- Arcing in terms of technology:
  = higher particle density caused by aluminum particles
- Arcing in terms of physics:
  = temporary local instability of plasma

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Why Arcing at STI etch in our AMAT MxP chambers appeared

- Basic reasons for arcing:
  - Hardware defects (i.e. scratches)
  - Normal waste of anodization
  - Potential differences between chamber parts
  - Critical process conditions (i.e. high RF power, polymers)
- Main arcing reason at STI etch in our MxP chambers:
  - Change of product mix: a new product uses a high polymerizing etch chemistry

  → The usual dry clean was not efficient enough for the new process mix, thicker polymer layers at the chamber wall

  → Arcing !

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How to get rid of arcing at STI etch in AMAT MxP chamber ?

- Extending clean time or increasing gasflows for the standard clean recipe is not a viable solution. It caused two effects:
  - Less arcing, yes.
  - But also a very strong first wafer effect on critical dimensions of product wafers, which could not be tolerated !

➔ Development of a new dry clean recipe was necessary:

- With effective polymer reduction on chamber walls.
- And with small tolerable CD degradation on product wafers.

➔ Development of a new dry clean using a different gas mixture.

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Strategy to develop a new dry clean

- 1. Basic experiments:
  - Test of other gas mixtures, e.g. CF_4/O_2, using resist test wafers
  - Target: High polymer etch rate
- 2. Evaluation of the new dry clean on product wafers:
  - Target: First wafer effect (critical dimensions !) negligible.
- 3. Long term evaluation of new dry clean on product wafers:
  - Target: New dry clean must be efficient enough
- Optimization between long term clean effect and first wafer effect on critical dimensions
- For the **efficient development** of the new dry clean we used a „quick and dirty“ real time in- situ process monitor - SEERS.

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Principle of SEERS

RF current
RF voltage

↓

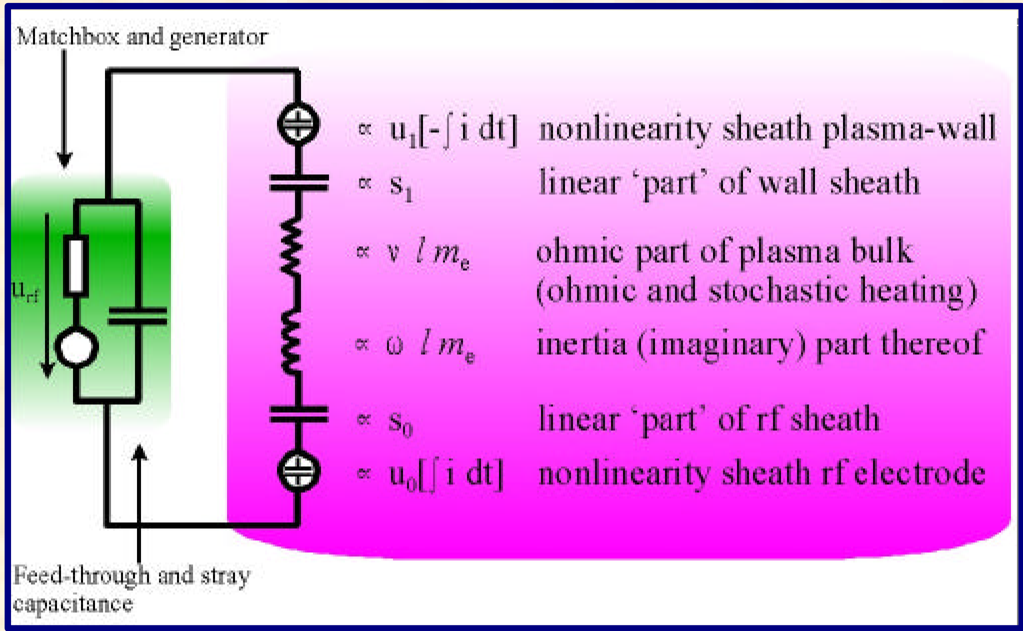
FFT

↓

Model SEERS

↓

Electron collision rate
Electron density
Bulk power
DC bias voltage



- Self Excited Electron Plasma Resonance Spectroscopy
  - Passive electrical method
  - Integral physical parameters

Experiments to optimize the new dry clean

- The new CF_4/O_2 dry clean recipe consists of two parts (like old one):
  - 1. Clean step – to remove the polymer
  - 2. Conditioning step – to minimize the first wafer effects on the following product wafers
- Experiments:
  - Optimization of clean step time, without subsequent conditioning step, using resist test wafers to monitor first wafer effect
  - Application of standard conditioning step, using product wafers
  - Fine tuning of conditioning time / recipe parameters on product wafers
  - Long term evaluation of new dry clean
- Targets of all these optimization experiments:
  - **Maximize** the polymer reduction at chamber wall
  - **Minimize** the first wafer effect on critical dimensions

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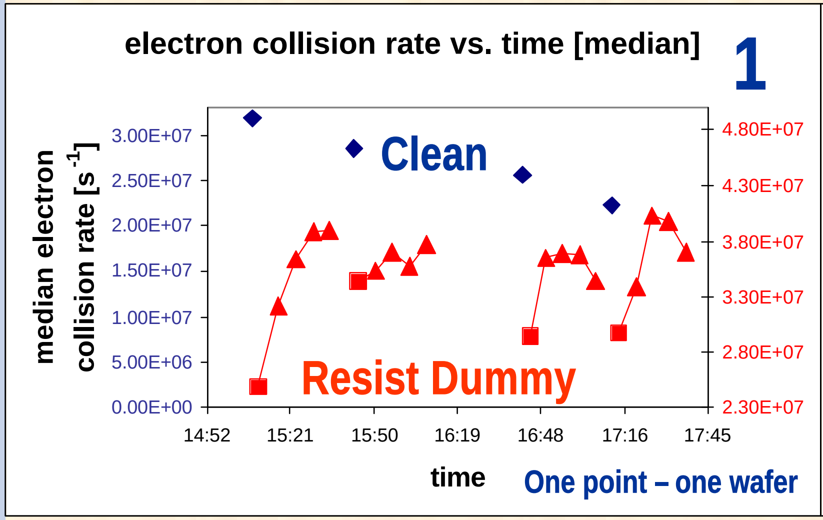
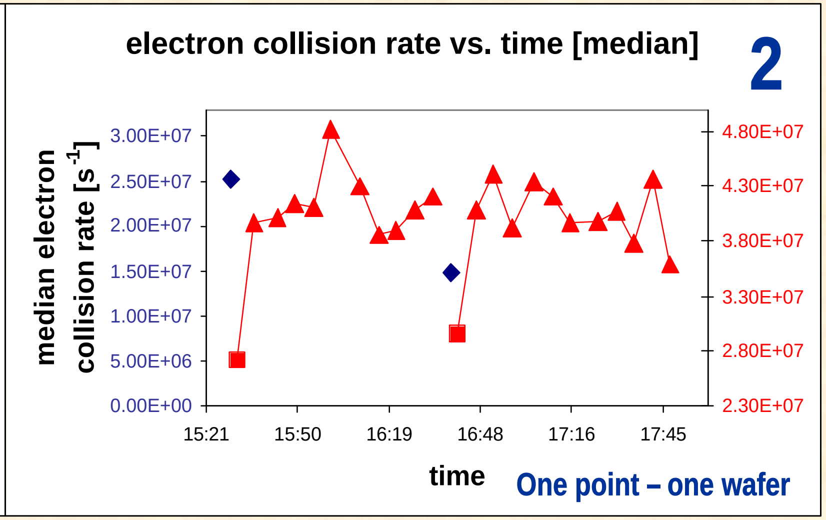
Optimization of clean step time (without conditioning step) using test wafers





- **Clean 1** is longer than **Clean 2**
- Clean step is performed without following conditioning step to monitor the impact of the cleaning process on chamber conditions.
- First wafer effect depends on cleaning process step time:
  - Dry clean 1: first wafer effect on 2 ... 4 following resist dummies
  - Dry clean 2: first wafer effect on 1 following resist dummy only

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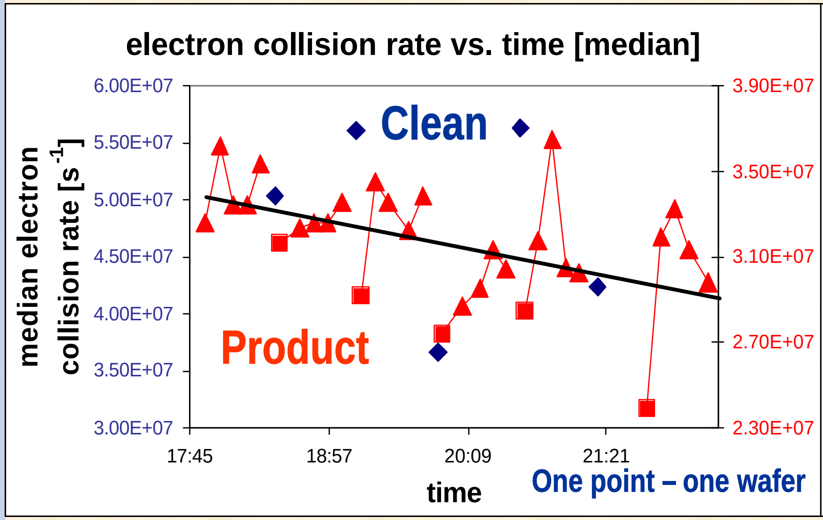
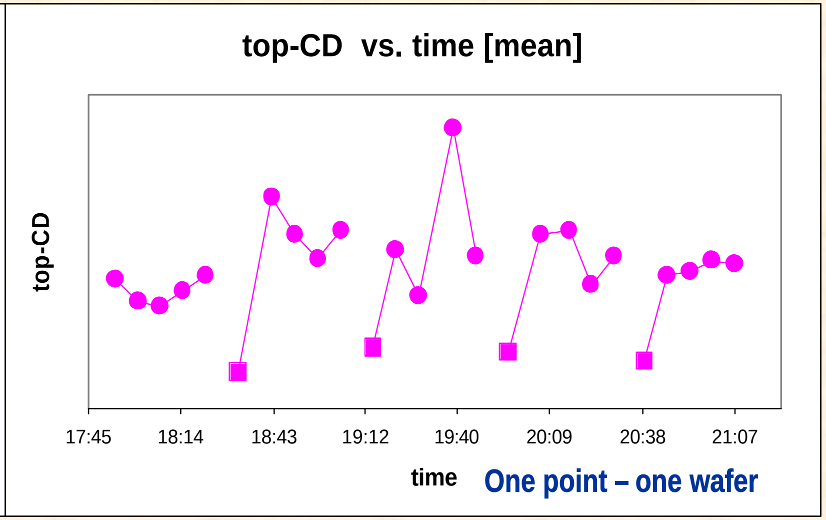
Conclusions from optimization of clean step time

- Dry clean 2:
  - Has a significant lower impact on chamber conditions.
  - Therefore we decided to use it for further optimization.
- Conditioning step after cleaning process:
  - Is applied to remove the first wafer effect completely.
  - But in case of to much conditioning the whole clean becomes inefficient, arcing could appear again.

  ➔ Finally long term tests of new cleaning process are necessary.

Application and optimization of conditioning step





- *Squares in diagrams represent first product wafer after each dry clean*

- Electron collision rate indicates first wafer effect on product wafers
- Electron collision rate also indicates drift of chamber conditions (decline of average represented by falling line in diagram)
- First wafer effect is also indicated by critical dimensions, measured on product wafers

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Conclusions from application of conditioning step

- Tested on product wafers
- First wafer effect, caused by dry clean, is indicated by electron collision rate.
- Additionally electron collision rate indicates drift of chamber conditions (declining average).
- First wafer effect is indicated by critical dimensions as, measured on product wafers.
- Chosen dry clean process with standard conditioning step has still significant impact on critical dimensions at STI etch.

➔ Conditioning time and / or conditioning recipe has to be changed to reduce influence on critical dimensions.

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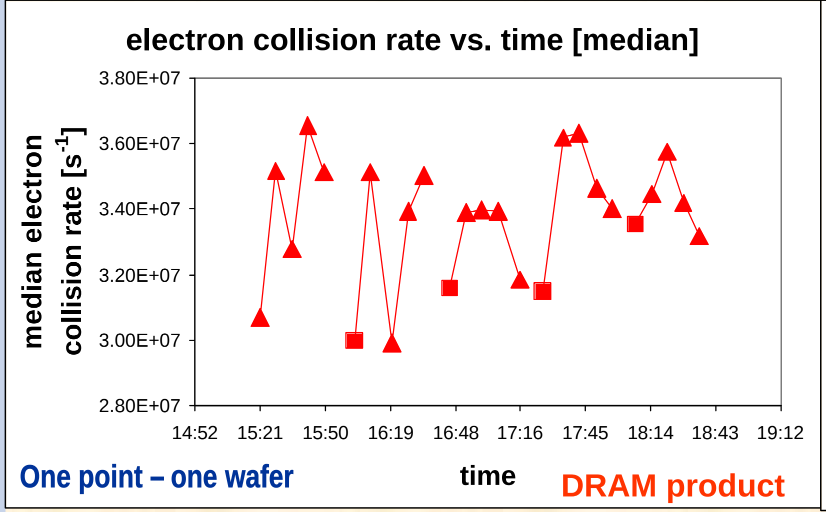
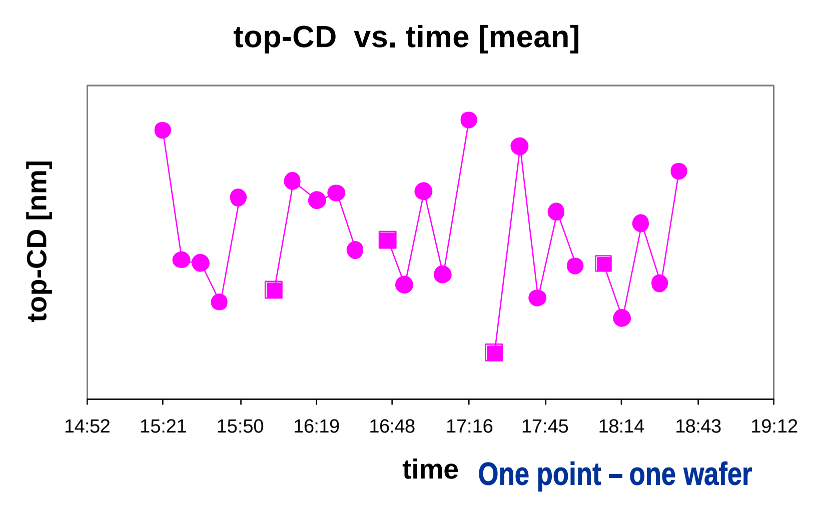
Modified conditioning step recipe



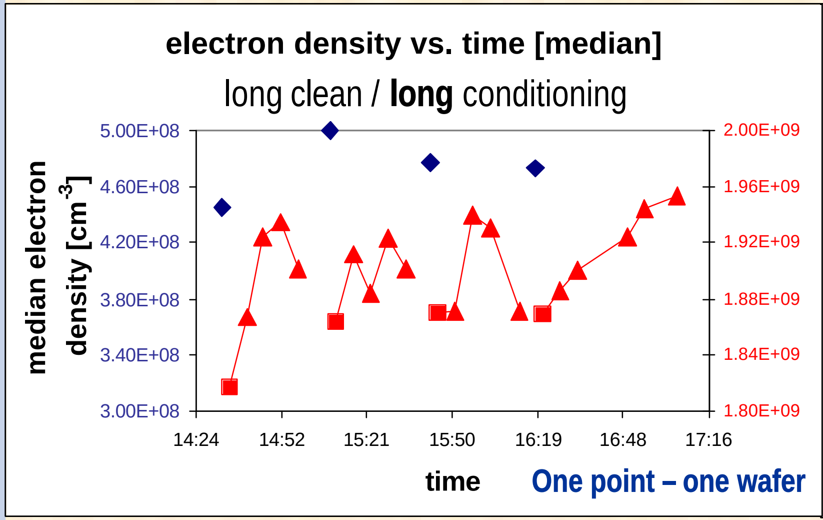


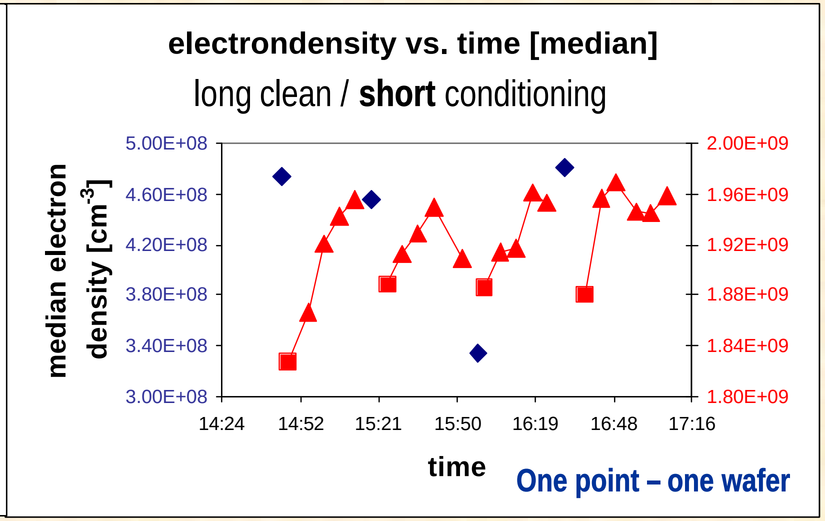
- *Squares in diagrams represent first product wafer after each dry clean*

- Now conditioning step has no CF_4/O_2, but clean-step is still with CF_4/O_2

➔ No significant first wafer effect after each dry clean
  - Now dry clean does not seem to have a big influence on critical dimensions & electron collision rate
- But: is dry clean still as effective?
  - *(Polymers are generated in the conditioning step and without CF_4/ O_2 even more ➔ possibly the clean effect is spoiled by the following conditioning step ?)*

Clean- and conditioning time optimization long vs. short conditioning





- *Squares in diagrams represent first product wafer after each dry clean*

- Optimization from economic point of view: Influence of cleaning- and conditioning time on chamber conditions
- Longer conditioning time does not seem to cause changes in trend of electron density for following resist wafers here

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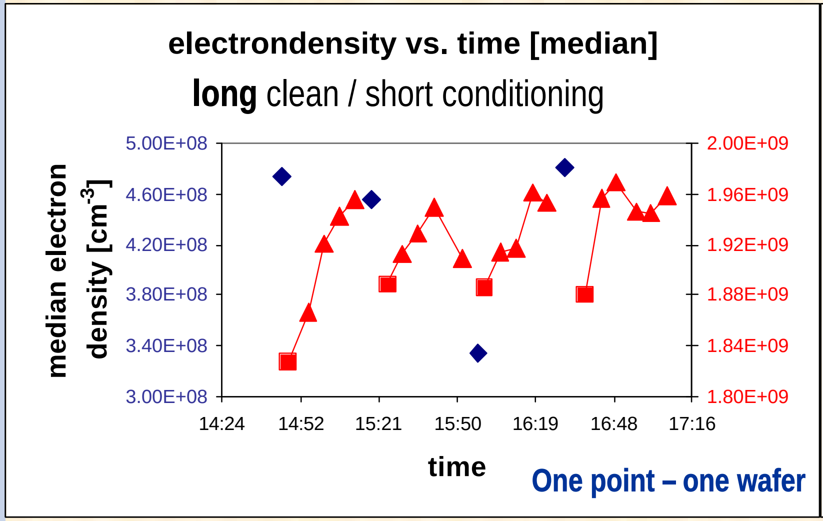
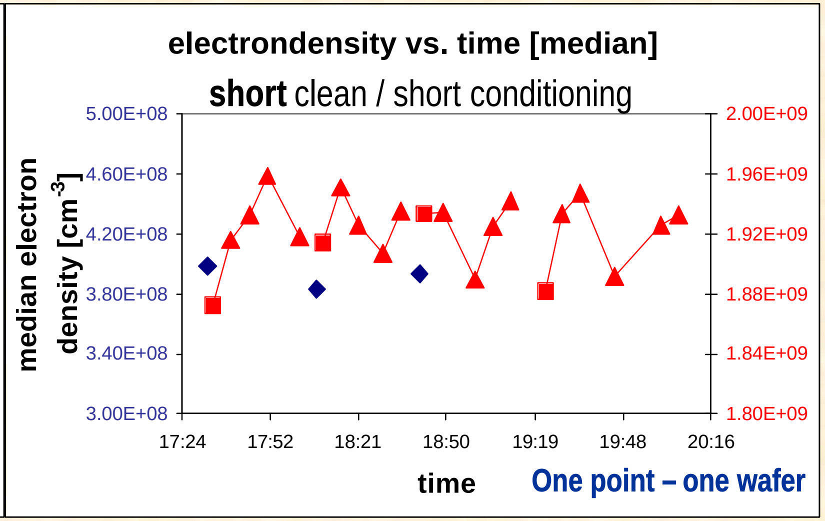
Clean- and conditioning time optimization long vs. short clean





- *Squares in diagrams represent first product wafer after each dry clean*

- Shorter clean time reduces first wafer effect on following resist test wafers
- But shorter clean time means less polymer reduction at chamber walls !

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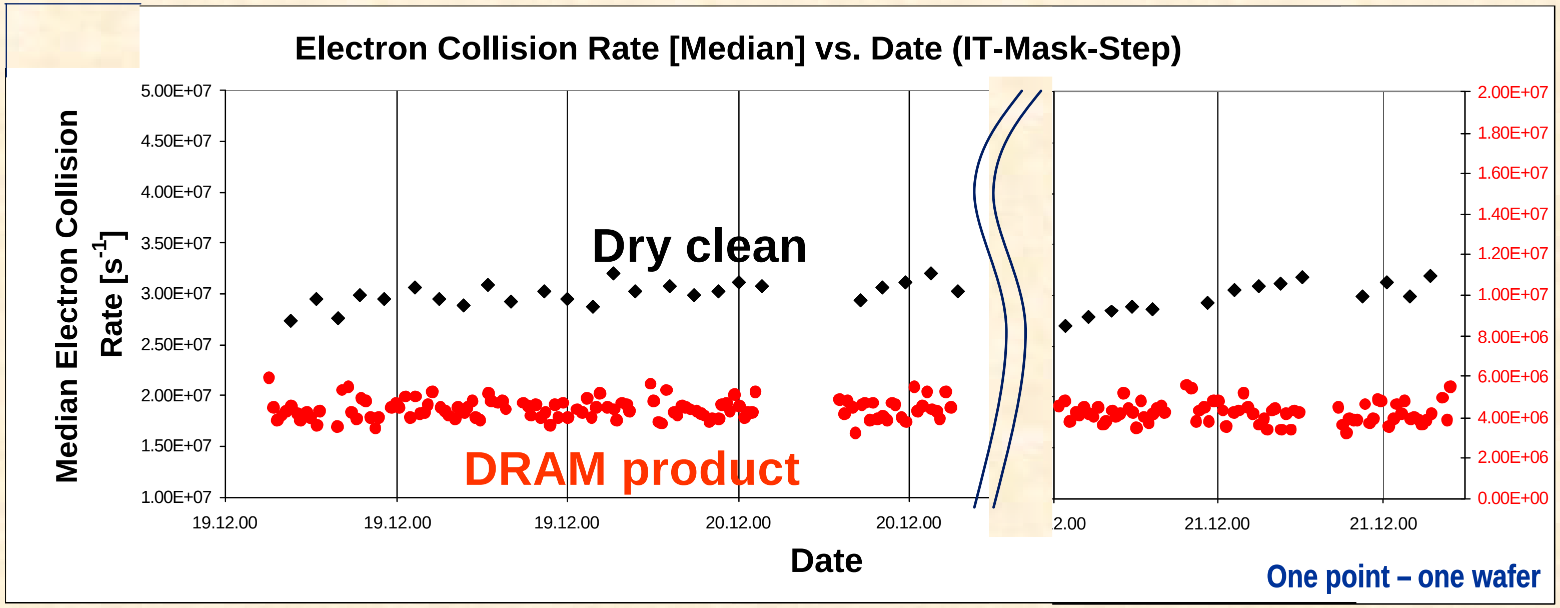
Long term evaluation of dry clean



- Long term evaluation of new dry clean in normal production shows no significant influence of dry clean on electron collision rate of DRAM- product wafers
- Only normal scattering (maybe because of pre- process tolerances) in electron collision rate

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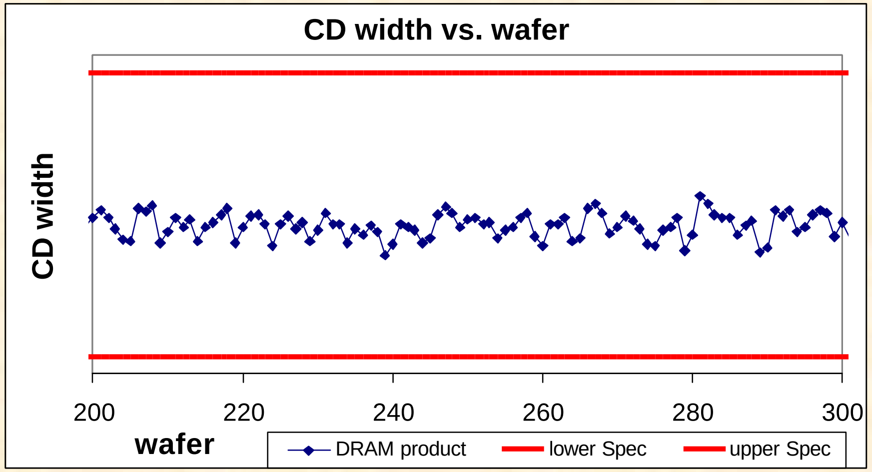
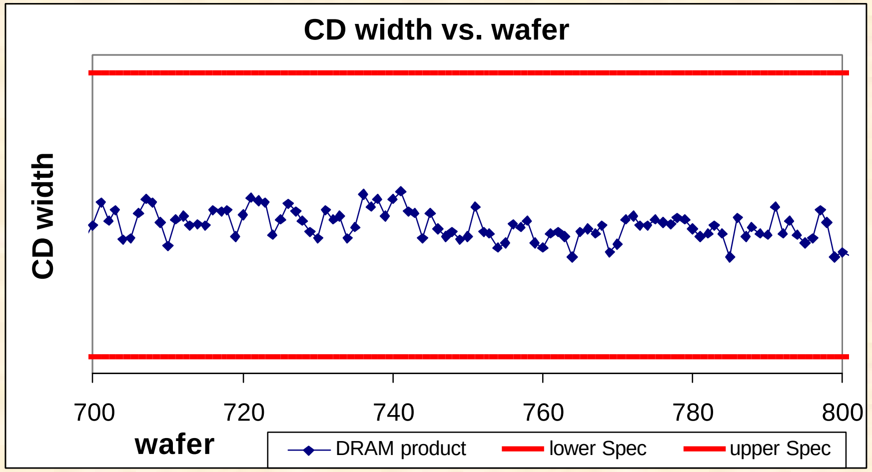
Dry clean impact on critical dimensions - Comparison of old and new dry clean



- Old dry clean
  - Critical dimensions in spec

- New dry clean
  - Critical dimensions in spec too
  - New dry clean has no significant influence on critical dimensions



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Summary I: Benefit of plasma parameters

- Electron collision rate and electron density have been used to optimize a new clean recipe at Shallow Trench Isolation etch in AMAT MxP chamber.
- Both plasma parameters show **in real time**
  - Dry clean impact on chamber conditions and first wafer effect on product wafers
  - **And** superimposed long term drift effects of chamber conditions
- Because plasma parameters do indicate chamber condition drifts, they can be used to monitor cleaning efficiency with respect to wall polymers.
- Therefore plasma parameter measurements can significantly help to improve efficiency & reduce costs of dry clean process development.

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Summary II: Dry clean optimization

- Benefits of new dry clean:
  - Has **no** significant **impact** on critical dimensions of following product wafers (as shown in short- and long- time observations)
  - Is **shorter** than old dry clean ➔ higher throughput
  - **Better clean efficiency** than old dry clean (as observed during chamber opening for maintenance purposes)
  - Chamber up time has been extended by longer dry clean period

➔ All targets of dry clean optimization (maximize polymer reduction from walls and minimize first wafer effect on critical dimensions) have been reached in short period of time using in-situ plasma monitoring techniques.

➔ Risk of arcing reduced.

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