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
Introduction - STI etch process

STI etch process - Overview

a) Starting profile

b) Mask-open step

c) Trench etch step

d) Oxide CVD

e) Planarization

f) A-B:

top-CD Oxide bottom-CD
Arcing – what’s that?

- Arcing in terms of technology:
  = higher particle density caused by aluminum particles

- Arcing in terms of physics:
  = temporary local instability of plasma

Fig.: Arcing generated Aluminum particle on wafer surface
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!
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.
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.
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

Development of new dry clean
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
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
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 too 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
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.
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?)

Optimization of 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

Time optimization
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!

Time optimization
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.
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

**CD width vs. wafer**

- **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
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.
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.

Summary