18 May 2017

World Semiconductor Council

Best Practice Guidance for Semiconductor PFC Emission Reduction

In order to effectively and efficiently achieve World Semiconductor Council (WSC) post-2010 voluntary PFC (Perfluoro-compound) emission reduction program, this technical guidance is set as the best practices for WSC members' reference and should not be viewed or applied as a standard. Implementation of identified best practices will vary among members based on availability for specific applications and feasibility. Emissions estimation protocol used will be based on WSC member agreement.

The elements of the 2020 goal include the following:

- The implementation of best practices for new semiconductor fabs. The industry expects that the implementation of best practices will result in a Normalized Emission Rate (NER) in 2020 of 0.22 $kgCO_2e/cm^2$ equivalent to 30% NER reduction from 2010 aggregated baseline.

- The addition of "Rest of World" fabs (fabs located outside the WSC regions that are operated by a company from a WSC association) in reporting of emissions and the implementation of best practices for new fabs.

- A NER based measurement in kilograms of carbon equivalents per area of silicon wafers processed ($KgCO_2e/cm^2$) that will be a single WSC goal for the semiconductor industry at the global level. This goal should not be applied to individual regions, companies or facilities.

Semiconductor fabs which break ground after May 2011 are considered to be new fabs and must employ the WSC best practices.

Best practices will be reviewed and updated by the WSC.

1. Emission Estimates:
   The WSC goal was established based on estimation method using "2006 IPCC Guideline for National Greenhouse Gas Inventories, Volume 3, Chapter 6" (IPCC GL) [5.1] and the Fourth Assessment Report (AR4) GWP values [5.2] .

2. Best practices.

   The selection of the best practice for a specific situation will depend on several factors such as viability, efficiency and other considerations.

   2.1. Process recipe optimization
   Optimizing processes to consume less greenhouse gases is a fundamental practice to be done for PFC emission reduction. Note: See chapter 3.1 and 3.2 for details.

   2.2. Greenhouse Gas replacement
   Replacing high global warming potential (GWP) gases with lower GWP or GWP-free gases or using gases more efficiently in the plasma process are another solution to further reducing net PFC emission. Note: See chapter 3.2 for details.

   2.3. Point of use (POU) Abatement
   An abatement system is used to reduce greenhouse gases by destructing the PFCs. POU abatement may be capable of treating PFC gases and hazardous gases simultaneously

   Note: See chapter 3.3 for details.

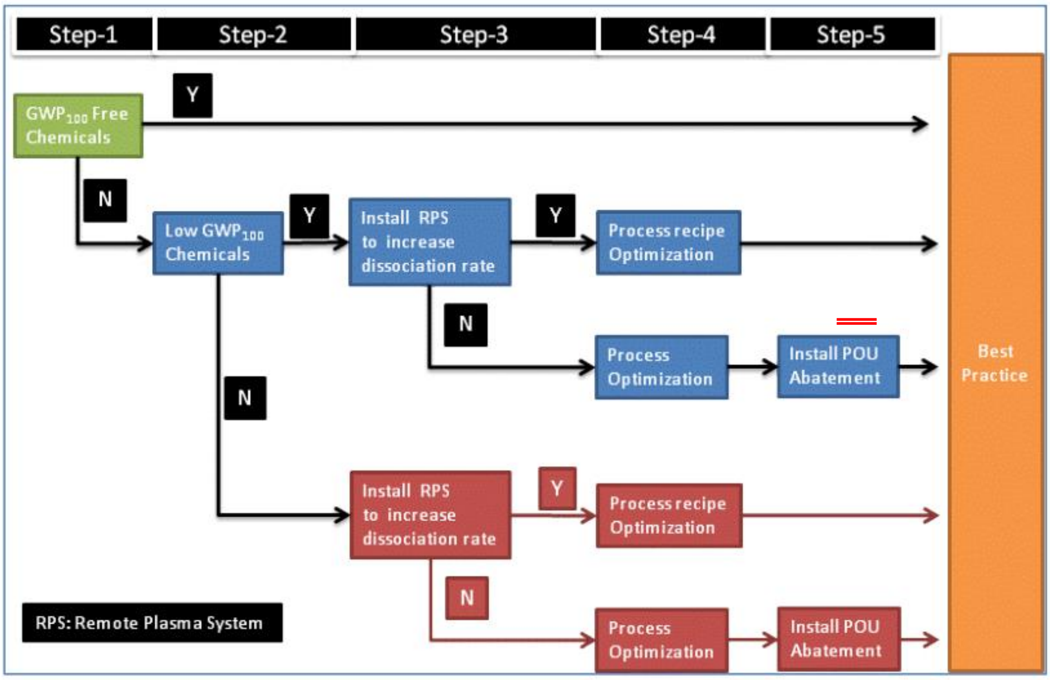
PFC abatement can be applied to:

- New fabs
  - All new fab construction
- Existing fabs
  - Maintain or replace existing installed abatement capacity
  - Existing Tools relocated to different regions should include abatement
  - Upgrade of existing tool, installation of new tool in existing fabs, and major retrofits as infrastructure allows, and is feasible

2.4. Remote Plasma Cleans

This is the best way to enhance the NF_3 dissociation rate in CVD chamber cleaning. It can reduce the amount of gases used and also significantly reduces PFC emissions when compared to other PFC gases used in CVD such as C_2F_6. Note: See chapter 3.4 for details.

2.5. Example of the best practice selection flow



3. Reduction methodology

3.1 Process recipe optimization

- **General technology Description**

  Process optimization allows emission reduction by adjusting process parameters such as the chamber pressure, temperature, plasma power, cleaning gas flow rates, gas flow time, and gas ratios in the case of mixtures. Process optimization can be applicable to both chemical vapor deposition (CVD) chamber cleans and etching processes.

  Process optimization can sometimes be accomplished by using an endpoint detection system, which uses techniques such as MS, infrared (IR) spectroscopy, optical emission spectroscopy (OES), and radio frequency (RF) impedance monitoring to monitor changes and provide plasma process end-point times. Endpoint detection has been used extensively for CVD chamber cleans, but the technology can also be applied to etch and other PFC plasma processes.

- **Applicability**

  Process optimization is applicable to ≤150 mm, 200 mm, and 300 mm CVD reactors and to other process tools using PFCs. A significant amount of work has been previously published on process optimization.

3.2 Gas Replacement Chemistry

- **General Technology Description**

  Alternative chemistry, or chemical substitution, is the use of chemicals with lower global warming potential (GWP_{100}) or GWP_{100} free as alternatives to PFCs. Alternative chemistry also includes high GWP_{100} gases that are more efficiently used in plasma processes, resulting in an overall greenhouse gas emissions reduction.

  When considering alternative chemicals, it is essential also to consider their potential safety and health impact to fab operations, employee protection, and external environmental impacts.

- Applicability

  The usage of low GWP_{100} Chemicals and

  GWP free chemicals depends on the specific processes (e.g., C_4F_6 for certain etching processes).

  In some cases it is appropriate to use high GWP_{100} gases that are more efficiently used in plasma processes which results in lower emissions (e.g., Nitrogen Trifluoride (NF_3)).

3.3 POU Abatement and recovery

- General technology Description

  Many new PFC abatement technologies have been developed and new systems commercialized [5.3]. The industry historically has favored POU over centralized EOP (End of Pipe) abatement for PFCs, finding that it is typically more effective to abate emissions close to the source before the exhaust stream is further contaminated and diluted.

  Although some countries and industry consortia have developed methods to determine abatement destruction/removal efficiency (DRE) [5.4, 5.5, 5.6], industry has not universally adopted a standardized method for determining the destruction/removal efficiency. Moreover performances of abatement systems varies greatly depending on a variety of abatement devices and process parameters such as temperature, PFC inlet concentration, flow rate, pump purge rates, overall inlet stream composition, etc. All measurement methods must account for dilution through the system.

- Applicability

  Technologies under development or proven to be effective in abating PFC emissions are listed as follows:

  - POU fueled combustion-wet scrubber
  - POU absorption-wet scrubber
  - POU plasma

- POU electrically heated thermal-wet scrubber
- Capture/recovery technologies (membrane separation, cryogenic recovery, and pressure swing adsorption/desorption) have been evaluated by the industry but have not been proven as viable technology.

3.4 Remote Plasma Cleans

- General technology Description
  Remote plasma clean technology was developed as an alternative to in situ CVD chamber cleans to clean the residues left in the chamber after deposition. With remote plasma clean, a plasma-generating unit is mounted on the lid of a CVD chamber. Remote cleans typically react NF3 in a plasma. The fluorine radicals and ions generated in the remote plasma unit are routed to the processing chamber where they chemically react with deposits. The deposition byproducts are then carried away in gaseous form, e.g., SiF_4.
- Applicability
  Technology is commercially available for some 200 mm and 300 mm CVD chamber cleans. Tool suppliers manufacture or integrate remote plasma systems for retrofits to some existing process tools to replace in situ PFC cleans.

3.5 New technologies will continue to be evaluated and shared among WSC PFC WG. Best Practice document will be reviewed for updates.

4. Evaluation of new technologies

In case companies want to measure emissions or want to determine the effectiveness of new technologies, reliable measurements protocols have to be followed. Examples of such protocols are given in the references (chapter 5).

5. References

5.1. 2006 IPCC Guideline for National Greenhouse Gas Inventories, V3, Chapter 6, http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/3_Volume3/V3_6_Ch6_Electronics_Industry.pdf.

5.2. Intergovernmental Panel on Climate Change (IPCC), Fourth Assessment Report (AR4), Working Group 1, Chapter 2, Changes in Atmospheric Constituents and Radiative ForcingTable 2.14, page 212,

http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_wg1_report_the_physical_science_basis.htm

5.3. "Reduction of Perfluorocompound (PFC) Emission: 2005 State-of-the-Technology", International SEMATECH Manufacturing Initiative (ISMI), Technology Transfer #05104693A-ENG.

5.4. "Guideline for Characterization of Semiconductor Process Equipment – Revision 3", SEMATECH Technology Transfer #06124825C-ENG, http://www.sematech.org/docubase/document/4825ceng.pdf.

5.5. JEITA Guideline for F-GHG Characterization and Management, October, 2011, http://semicon.jeita.or.jp/committee/docs/F-GHG_guideline_20110520_en.pdf.

5.6. US EPA Protocol for Measuring Destruction or Removal Efficiency (DRE) of Fluorinated Greenhouse Gas Abatement Equipment in Electronics Manufacturing, Version 1, https://www.epa.gov/sites/production/files/2016-02/documents/dre_protocol.pdf.

5.7. US EPA Greenhouse Gas Mandatory Reporting Rule, Subpart I, http://www.ecfr.gov/cgi-bin/text-idx?SID=a8058176db91462ef40c742dd2e236d4&mc=true&node=pt40.23.98&rgn=div5#sp40.23.98.i.

6. Periodic review

In order to keep updating PFC reduction technologies developed, WSC PFC WG shall review/update and make available this guidance every two years.

- February 2014
- February 2016
- February 2018
- February 2020