March 9, 2011

Tucson, AZ

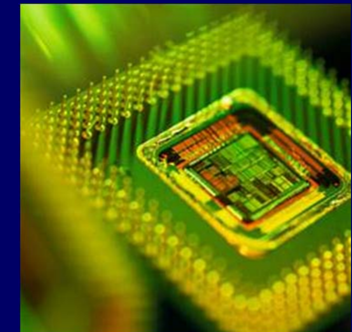
Accelerating Sustainable Manufacturing

Emerging Research Topics Workshop: Process Greenhouse Gases

Laurie Beu

Consultant to ISMI

Laurie.Beu@ismi.sematech.org



Copyright ©2010
Advanced Materials Research Center, AMRC, International SEMATECH Manufacturing Initiative, and ISMI are servicemarks of SEMATECH, and the SEMATECH logo are registered servicemarks of SEMATECH, Inc. All other servicemarks and trademarks are the property of their respective owners.

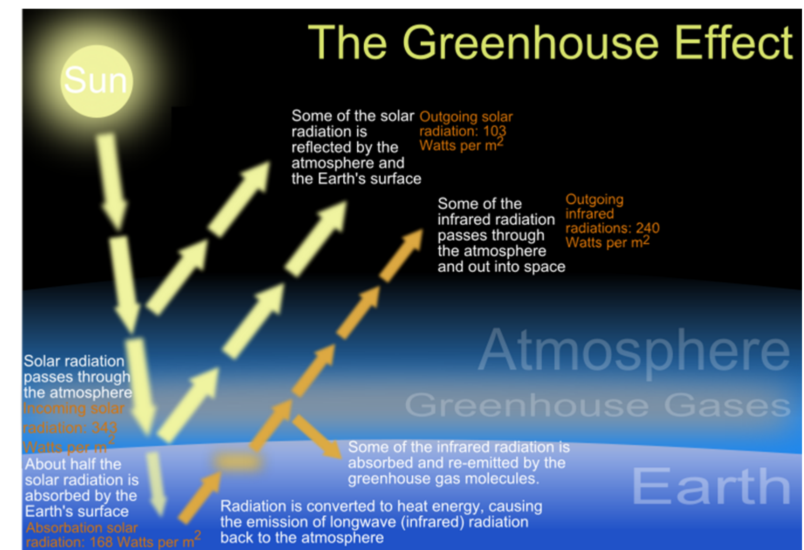
Why Focus on Semiconductor Process Fluorinated GHG and Fluorinated heat transfer fluids?

- Synthetic gases and fluids.
- Excessively long atmospheric lifetimes.
- Strong infrared absorption capacity.
- Largest GWPs of any greenhouse compounds.

Compound	Lifetime	GWP_{100}
Carbon Dioxide	variable	**1**
Methane	12	**25**
Nitrous Oxide	114	**298**
Select HFC, PFC, fluorinated ethers		
CHF_3	270	**14,800**
CF_4	50,000	**7,390**
C_2F_6	10,000	**12,200**
C_3F_8	2,600	**8,830**
$c\text{-}C_4F_8$	3,200	**10,300**
NF_3	740	**17,200**
SF_6	3,200	**22,800**
HFE-125	136	**14,900**
HFE-134	26	**6,320**
HFE-7100	3.8	**297**

Overview of Semiconductor Greenhouse Gas (GHG) Emissions

- Majority of Semiconductor GHG emissions due to energy usage (~70-90%)
- Process emissions account for (~10-30%) and include:
  - Fluorinated Greenhouse Gases (F-gas)
    - CVD Chamber clean and Plasma Etch
  - Nitrous Oxide (N_2O)
    - Silane-based oxide CVD
    - Furnace Nitride
  - Fluorinated Heat Transfer Fluids (F-HTFs)
    - Process Equipment Chiller Units



Semiconductor Industry GHG Emissions Reduction History

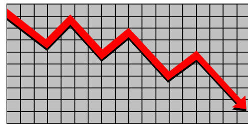
- 1996 – SIA members signed PFC emissions reduction partnership voluntary agreement with EPA – committed to estimating emissions and endeavoring to reduce.
- 1996 – ERC in EBSM formed – research areas included alternative etch and cleans chemistries and F-gas abatement.
- 1999 – SIA signed MOU2.
- 1999 - World Semiconductor Consensus Goal - 10% reduction in absolute PFC emissions from baseline by 2010.
- 2010 –EPA issues tailoring rule requiring new source and Title V permits for major sources of GHG emissions and Mandatory Reporting Rule for Electronics Manufacturing Facilities.

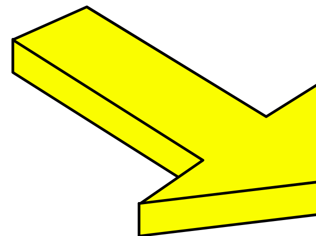
Industry GHG reduction efforts are transitioning from voluntary to regulatory.

Fluorinated GHG Emissions Reduction Options

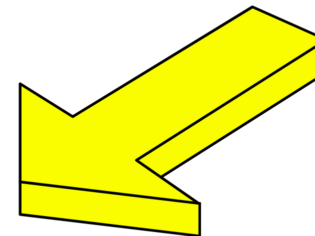
INTERNATIONAL SEMATECH
ISMI
MANUFACTURING INITIATIVE
ESH Technology Center

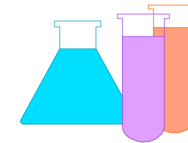
PROCESS OPTIMIZATION / ALTERNATIVE PROCESSES



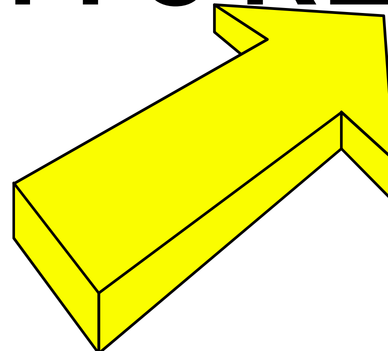


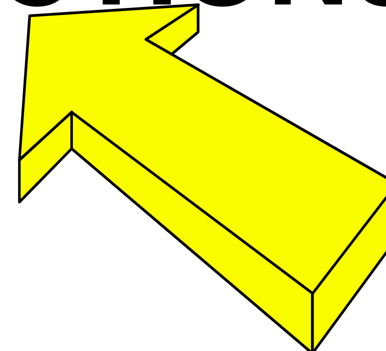
ALTERNATIVE CHEMISTRIES

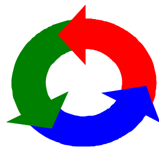




PFC REDUCTIONS

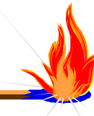






RECLAIM/RECYCLE

ABATEMENT

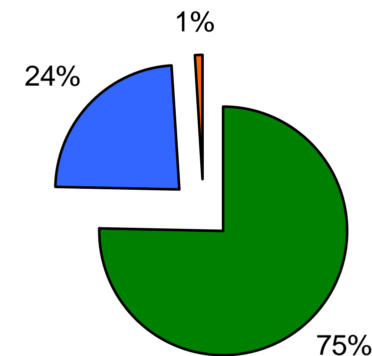


Presented 19-May-2010 to EPA by Laurie Beu

Percent of Total 2009 F-GHG Used per Process Category Based on Survey Responses

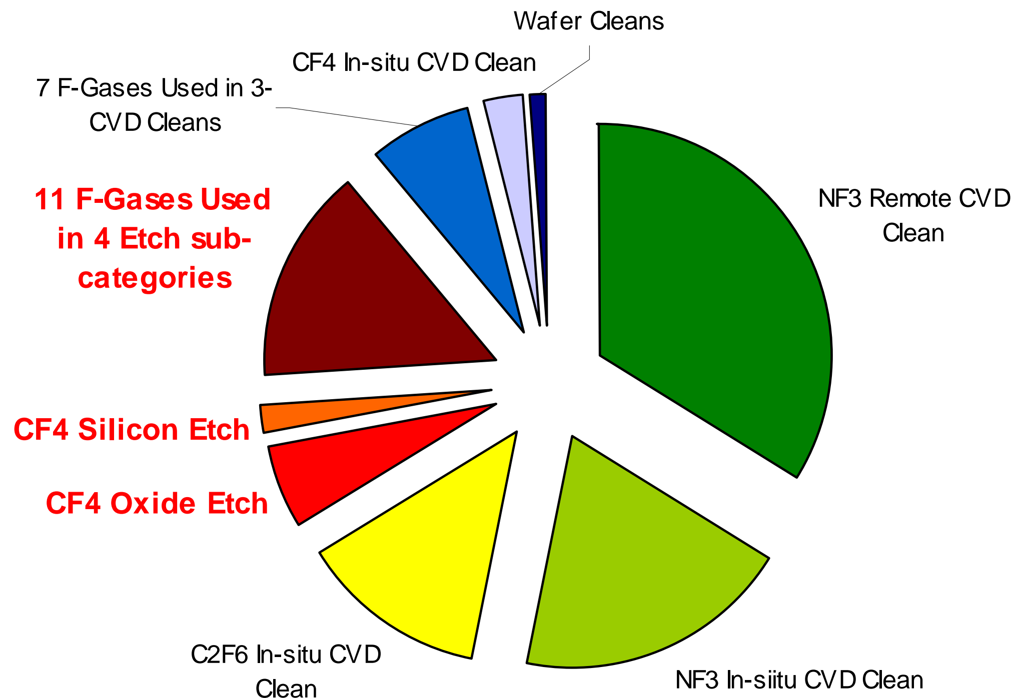
Process Sub-category	≤150mm total (5 fabs)	200mm total (11 fabs)	300mm total (12 fabs)
In-situ plasma	5%	16%	13%
Remote plasma	1%	8%	32%
In-situ thermal	—	0.02%	0.2%
Silicon	1%	1%	3%
Oxide	2%	3%	6%
Nitride	0.5%	1%	3%
Metal	1%	0.03%	2%
Bevel Clean	—	0.0002%	0.3%
Ashing	0.04%	0.7%	0.2%
% of Total F-GHG Used	10%	29%	61%

2009 F-gas Usage Totals per Category



- No apparent need for In-situ thermal, Bevel Clean and Ashing categories.
- Chamber cleans comprise 75% of total gas usage.
- Etch usage on a per technology, per category basis is minor portion of total F-Gas usage.
- Different default emission factors per technology may not be necessary.

F-GHG Use in CVD Cleans Are Largest Industry Uses, Not Etch



Industry Actual F-GHG use ranking:

- 1st: NF_3 for remote CVD clean ~34%
- 2nd: NF_3 for in-situ CVD clean ~19%
- 3rd: C_2F_6 for in-situ CVD clean ~13%
- **4th: CF_4 for oxide etch ~6%**
- 5th: CF4 for In-situ CVD clean ~3%
- **6th: CF4 for silicon etch ~2%**

Changing Makeup of Process GHG Emissions – ≤ 200mm fabs

Older Fab Process Fluorinated GHG Emissions

Emissions

CH2F2
C4F8O
C5F8
NF3
SF6
CH3F
CHF3
c-C4F8
C3F8
C2F6
CF4

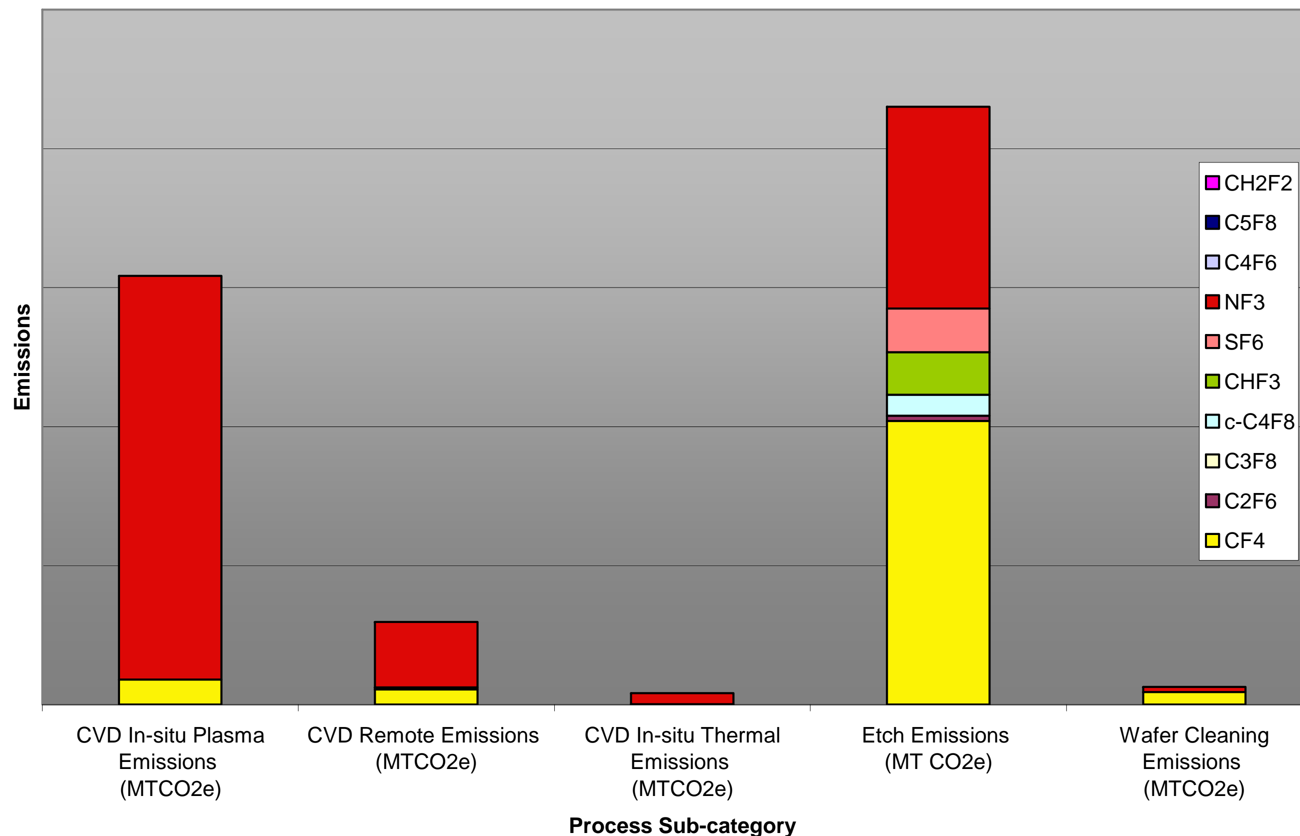
CVD In-situ Plasma Emissions (MTCO2e)
CVD Remote Emissions (MTCO2e)
CVD In-situ Thermal Emissions (MTCO2e)
Etch Emissions (MTCO2e)
Wafer Cleaning Emissions (kg CO2e)

Process Sub-category

Default emission factors applied to 2009 use data.

- Largest source of emissions – CVD chamber cleans.

Changing Makeup of Process GHG Emissions – 300mm fabs



Default emission factors applied to 2009 use data.

- Largest source of emissions – plasma etch.

Impact of Previous ERC Research

- ERC undertook significant research in F-gas abatement and alternative chemistries. Industry impact:
  - In-situ and remote NF_3 processes are utilized for 300mm equipment sets, significantly reducing CVD chamber clean F-gas emissions.
  - F-gas abatement technology has improved and is being utilized.

Emerging Research Needs

INTERNATIONAL SEMATECH ISMI MANUFACTURING INITIATIVE ESH Technology Center

- Plasma etch processes have become the leading source of 300mm process F-gas emissions.
  - New device architecture and the need to etch more complex structures (such as through silicon via etch using SF_6) are driving etch F-gas use and emissions higher.
- Research is needed to develop ***alternative etch chemistries with low/no GWP*** and ***new etch processes which do not utilize or emit high GWP gases***.

Additional F-gas Research Needs: Abatement

INTERNATIONAL SEMATECH ISMI MANUFACTURING INITIATIVE ESH Technology Center

- Combustion is the most widely used method for abating semiconductor F-gas emissions.
  - Technology efficiency is limited by a lack of basic information regarding the fundamental thermochemistry and kinetics of fluorochemical combustion.
  - Research is needed to understand and optimize **F-gas combustion abatement chemistry**, **abatement design** and **abatement operation**.