Damage Free and Energy Efficient Megasonic Cleaning

PIs:

- **Srini Raghavan, Materials Science and Engineering, UA**
- **Manish Keswani, Materials Science and Engineering, UA**

Graduate Students:

- **Zhenxing Han: PhD candidate, Chemical and Environmental Engineering, UA**

Core Funding Source:

- **Intel (mentors: Gopal Rao and Avi Fuerst)**

Cost Share:

- **ERC (~ $25k)**
- **IMEC: In kind donation of Patterned Wafers (~$5k)**

Objectives

Overall Objective:

- **Energy reduction in Megasonic Cleaning Processes**

Current Year Goal:

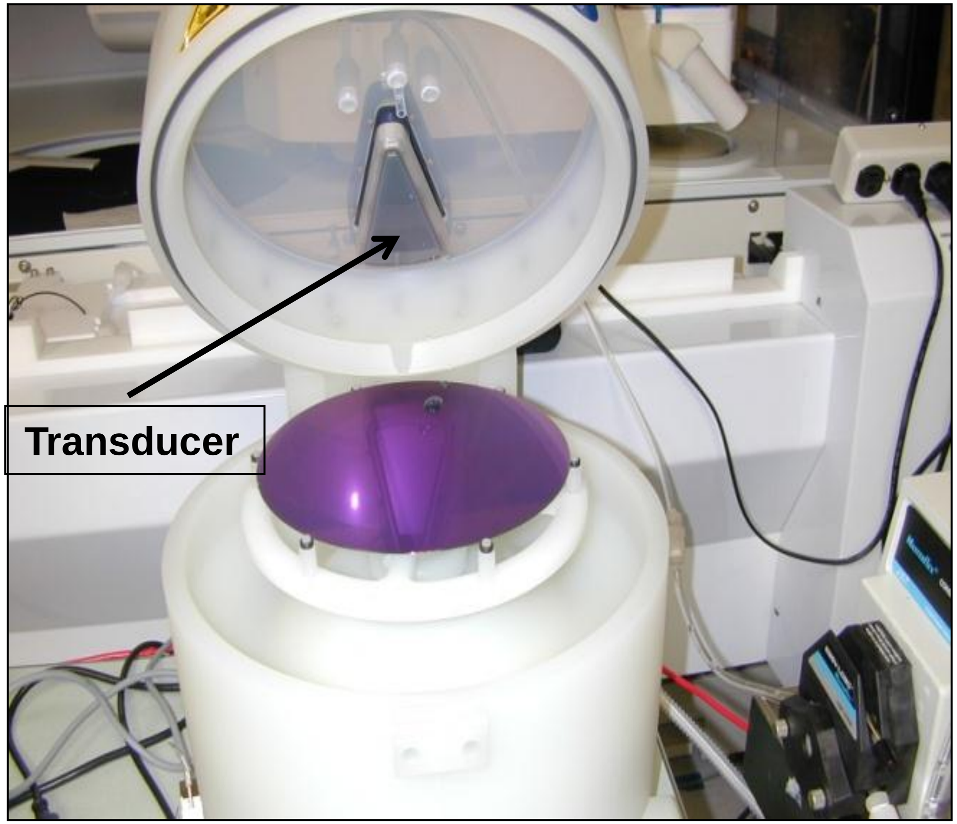
- **Development of a Chemical System for a Megasonic Cleaning Process that is able to achieve high particle removal efficiency (PRE) at low power density with significantly reduced feature damage**

ESH Metrics and Impact

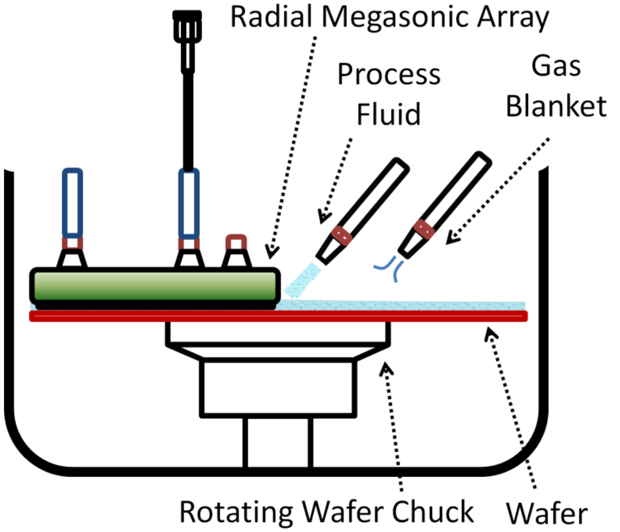
1. Cleaning formulations developed in this work use weakly alkaline pH (~8.2) to achieve effective particle removal as opposed to traditional cleaning formulations based on ammonium-peroxide mixtures (APM) that operate under more alkaline (pH > 10) conditions

2. Overall die/wafer yield improvement through reduction in feature damage by proper choice of cleaning chemicals and low transducer power density (energy)

Single Wafer MegPie® Set up for Cleaning and Damage Studies

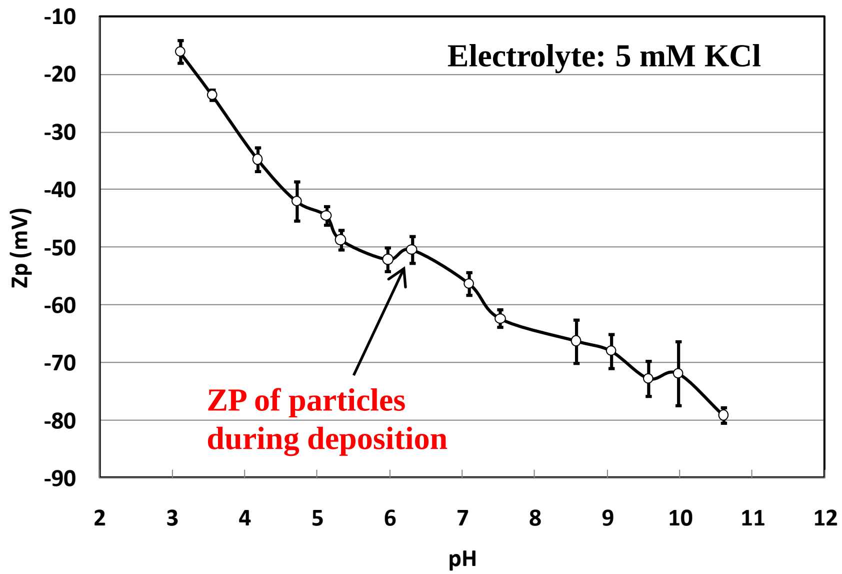


- Frequency ~ **925 kHz**
- Power density Range = **0.15 - 2.9 W/cm²**
- Active megasonic surface area = **32.3 cm²**
- Substrate to piezoelectric transducer distance ~ **1 mm**



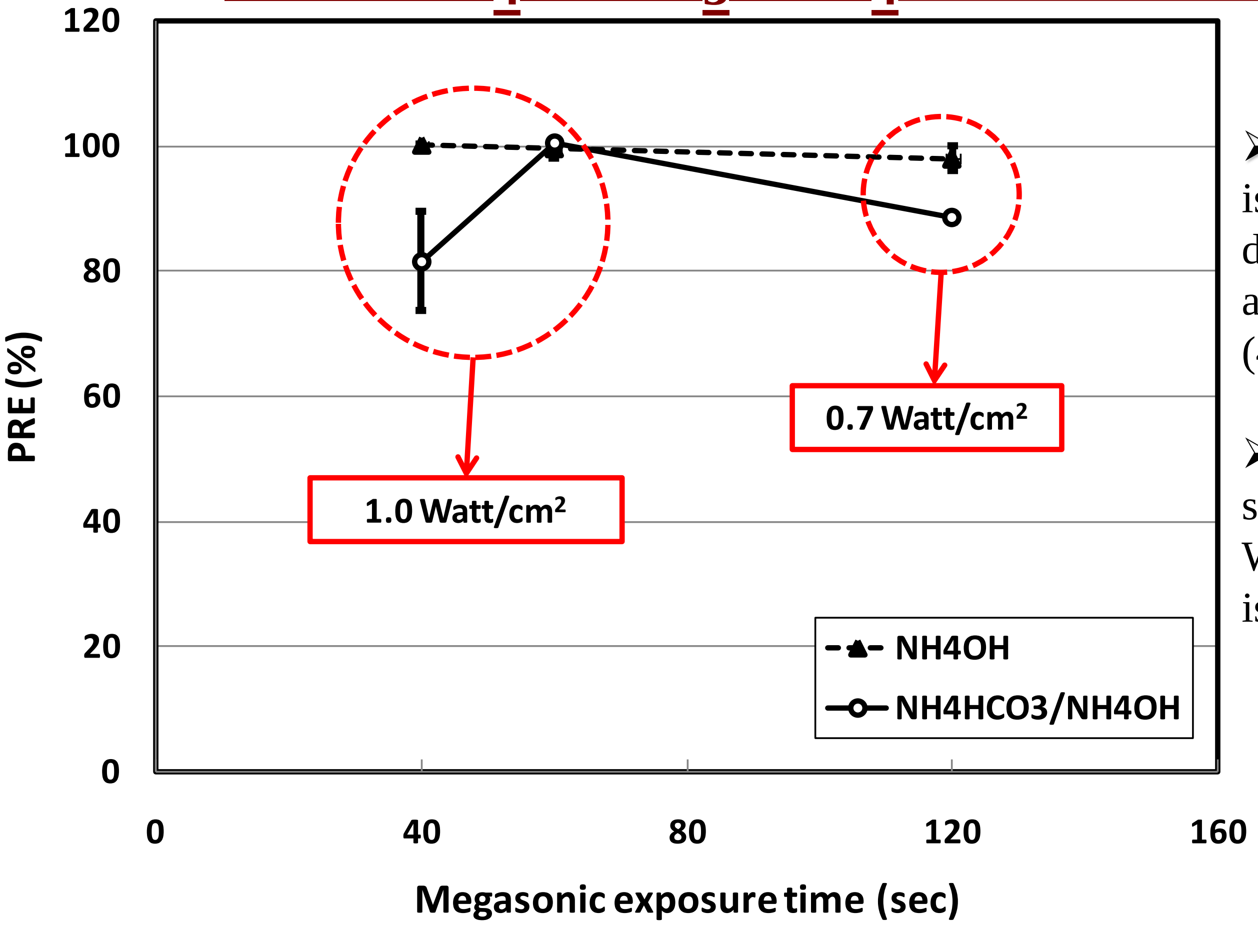
Procedure for Cleaning Study on Blanket Wafers

1. 8" oxide wafers pre-cleaned using dilute HF (1:100)
2. Silica particles (mean diameter ~200 nm) deposited on the wafer using spin deposition technique
3. ~4000 particles deposited per wafer and aged for 24 hr before cleaning
4. The contaminated oxide wafers cleaned in MegPie® under the following conditions:
    - Cleaning solution flow rate: 300 ml/min, wafer spin speed: 30 rpm.
    - Megasonic conditions: Power density: 0.7-1.0 W/cm^2, Exposure time: 40, 60 and 120 sec
5. Particle count measured using SP1 after deposition and cleaning



Zeta potential measurement of particles in the silica slurry

Cleaning Results on Blanket Wafers Using NH_4OH and NH_4HCO_3/NH_4OH solutions at pH 8.2

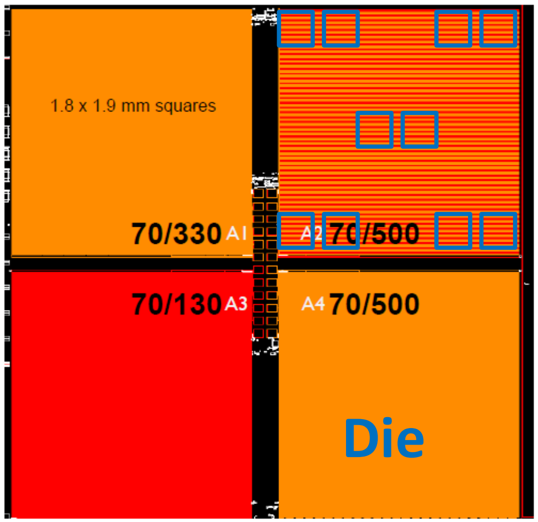


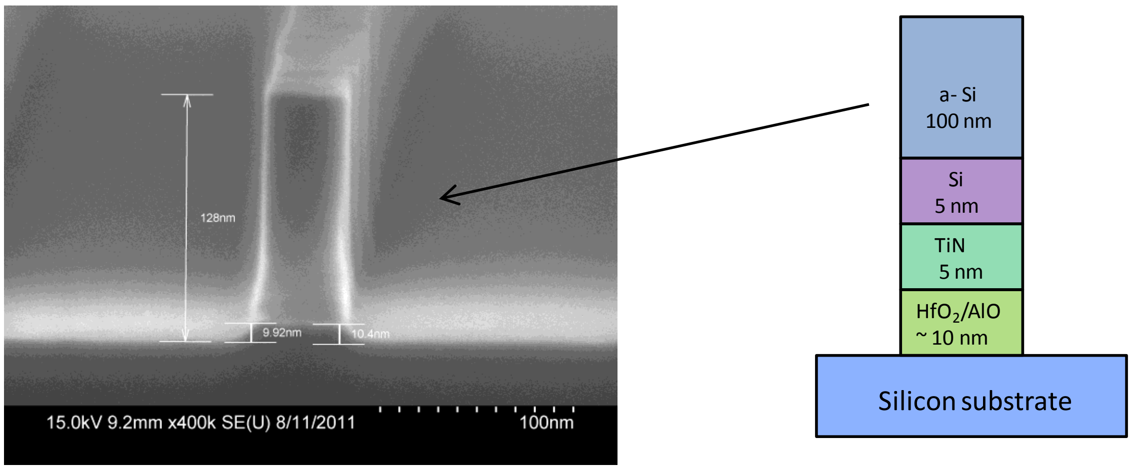
- In NH_4OH solution, 100 % PRE is achieved for investigated power densities (0.7 and 1.0 W/cm^2) and megasonic exposure times (40, 60 and 120 sec)
- In NH_4HCO_3/NH_4OH solutions, slightly higher power density of 1.0 W/cm^2 and cleaning time of 60 sec is required to achieve 100 % PRE

Proper choice of power density and cleaning time yields a 100 % PRE in NH_4HCO_3/NH_4OH solution (at pH of ~ 8.2)

Procedure for Cleaning and Damage Study on Patterned Samples

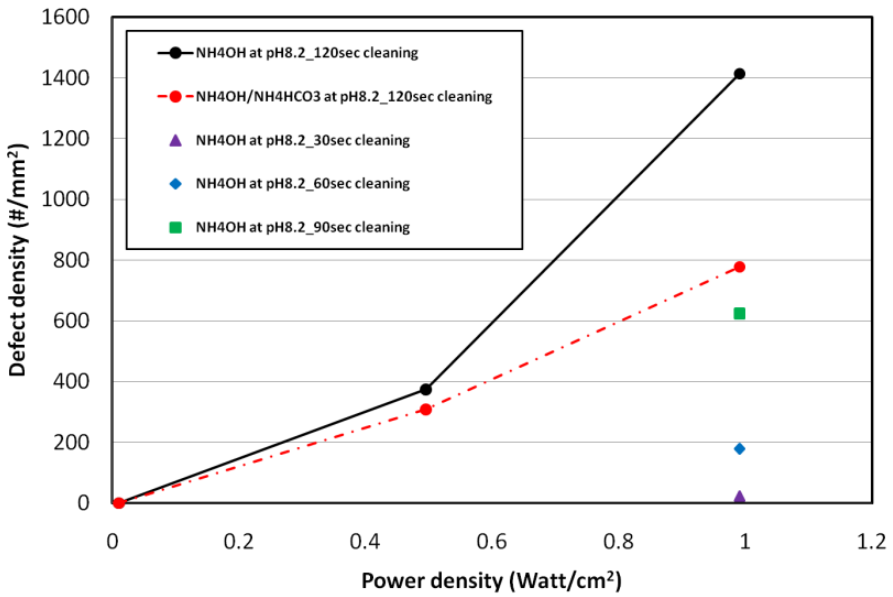
- Patterned wafers (high-k-metal gate) obtained from IMEC. The A2 section (1.8 mm x 1.9 mm) in the structure, which consisted of lines with 40 nm width (measured by SEM) separated by 500 nm, used for characterization.
- Leica DM4000 M microscope used for imaging; 10 regions each of 0.3 mm x 0.4 mm area imaged at a magnification of 200X.
- The images were then processed using the ImageJ software. It was established earlier that by adjusting suitable threshold value to the image, it is capable to distinguish between particles and defects.

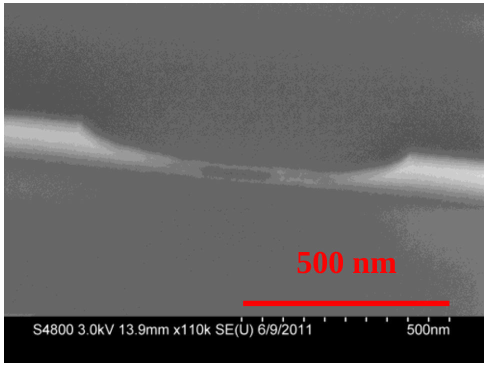


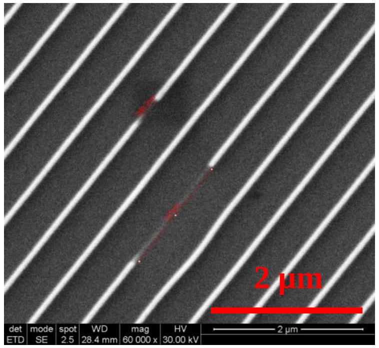


SEM showing multi-stack line on Si substrate

Effect of Power Density and Megasonic Exposure Time on Particle Removal and Feature Damage in NH_4OH and NH_4HCO_3/NH_4OH Solutions







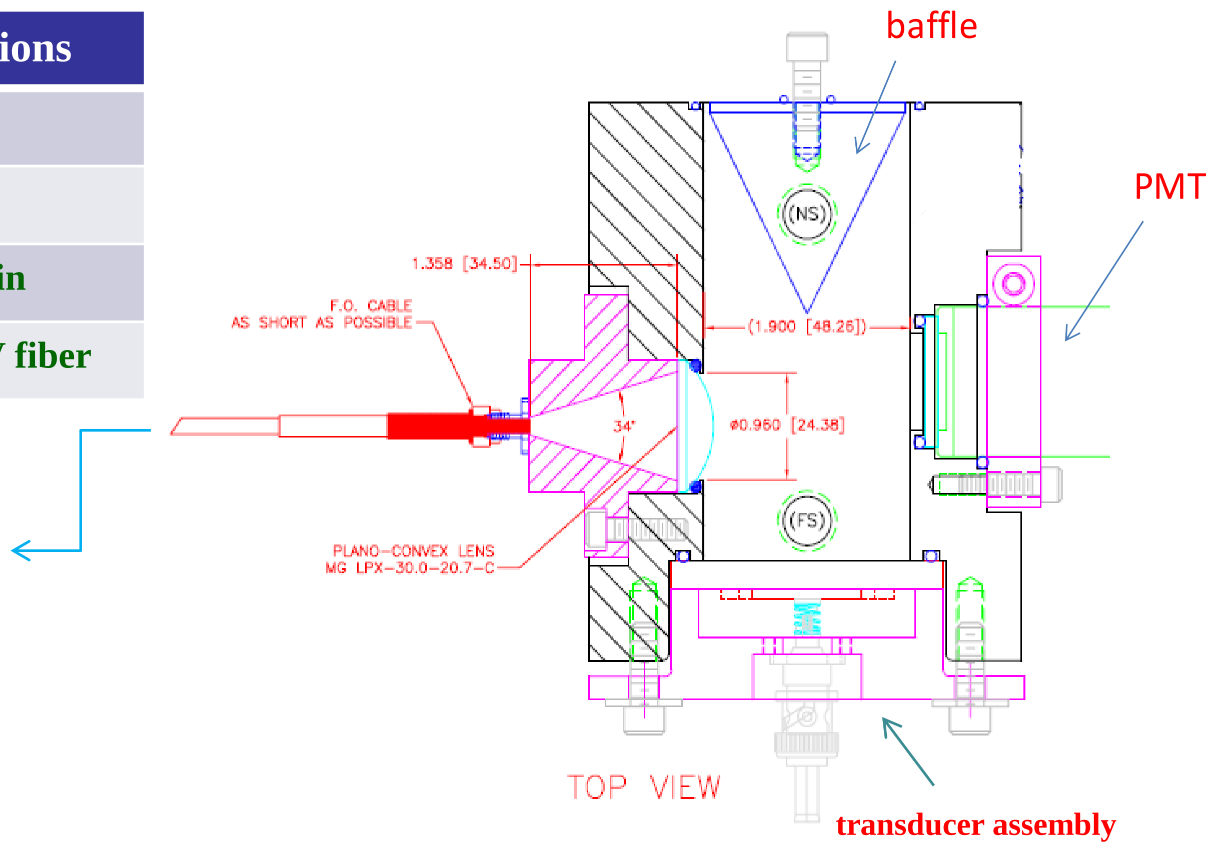
SEM image of typical defects on lines during megasonic exposure

Cleaning Solution	PRE (%) Power density of 1 W/cm^2 and meg exposure for 60 sec
NH_4OH	~ 95
NH_4OH/NH_4HCO_3	~ 94

- ➢High PRE achieved in both NH_4HCO_3/NH_4OH & NH_4OH systems at 1 W/cm^2 and 60 sec (meg exposure)
- ➢Damage to thin lines much higher in NH_4OH solution (pH ~ 8.2) compared to that in NH_4HCO_3/NH_4OH solutions at pH 8.2 for 120 sec of meg exposure; Defect study in NH_4HCO_3/NH_4OH system at lower meg exposure time in progress

Current Status on the CT Cell-Spectrometer Assembly

QE65000/FO cable Specifications	
Wavelength range	200-950 nm
Spectral Resolution	~ 5 nm
Integration time	8 ms – 15 min
FO cable	1000 µm UV fiber



A plano-convex lens (of diameter 3 cm) has been installed in the CT cell (opposite to the photo-multiplier tube) to have better light collection efficiency

Tests are being conducted to determine light focusing and transmission capability of the optical set-up

Industrial Interactions and Technology Transfer

- **Collaboration with ProSys, CA and technical discussions with Ocean Optics for design and construction of the optical set-up for integration of the spectrometer with the CT cell**

- **Filed an Invention Disclosure on 10/07/11 with University of Arizona on a novel chemical formulation developed for low damage and high PRE megasonic cleaning process. Ongoing discussions with Intel on filing a patent**

Acknowledgements

- **Dr. Sangita Kumari, Global Foundries, who worked during the first phase of the project**
- **Mark Beck and Eric Liebscher, ProSys, for help with modification of the CT cell and optical assembly**

Future Plans

Next Year Plans

- **Collect sonoluminescence spectra in ammonium bicarbonate based chemical system that has shown good cleaning with low feature damage**

- **Relate damage to high energy cavitation events during megasonic cleaning through spectral information**

Publications, Presentations, and Recognitions/Awards

- **S. Kumari, M. Keswani, S. Singh, M. Beck, E. Liebscher, L. Toan, and S. Raghavan, ECS Transactions, 41, 5, pp. 93-99 (2011)**

- **S. Kumari, M. Keswani, S. Singh, M. Beck, E. Liebscher, L. Toan, and S. Raghavan, Effect of Dissolved CO_2 in De-ionized Water in Reducing Damage During Megasonic Cleaning in MegPie, 220*th* *ECS Meeting*, Boston, MA, (Oct 9-14, 2011)**

Cost and Environmental Benefits of Biosorption of Copper from CMP Wastewater versus Ion Exchange

Lisa A. Jones, Dr. Kimberly Ogden, Mayrita Arrandale

Objective

Remove copper (Cu) from chemical mechanical planarization (CMP) wastewater with lipid extracted algae (LEA) from Chlorella protothecoides, a freshwater algae

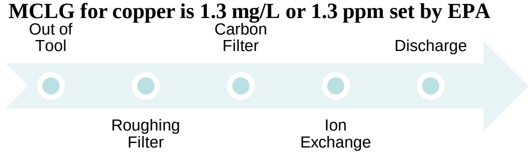
Background

- **Typical semiconductor facility or "fab" manufacturing 300 mm wafers produces approximately 57 liters of wastewater per wafer containing approximately 20 ppm copper**
- **Fab will generate over 17 million gallons of wastewater each year with 25,000 wafers per month out put**

Algae is being grown in record quantities for biodiesel; LEA is waste

CMP Effluent Flow Diagram

MCLG for copper is 1.3 mg/L or 1.3 ppm set by EPA



ESH Metrics and Impact

Reduction in emission of copper in wastewater from semiconductor manufacturing plants

- Current emissions are ~ 2 to 20ppm from CMP
- Chlorella sp. capable of removing ~10ppm Cu from water

Reduction in chemicals and goods currently used to remove copper from CMP waste streams

- Current methods use activated carbon and ion exchange resins to remove copper that require charging with acids: 10% by weight sulfuric acid

Industrial Interactions and Technology Transfer

Mayrita Arrandale, Research Scientist for Biological Technologies, Atotech

PIs:

- Dr. Kimberly Ogden, Chemical and Environmental Engineering, UA

Graduate Students:

- Lisa A. Jones, PhD candidate, Chemical and Environmental Engineering, UA

Undergraduate Students:

- Leanne Strauss, Chemical and Environmental Engineering, UA
- Mikala Mehlau, Biochemistry & Molecular Biophysics, UA

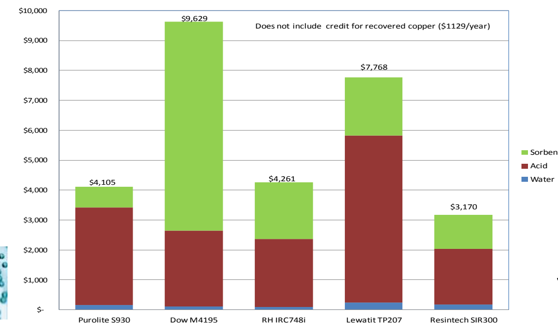
Cost Share (other than core ERC funding):

- $50k from Atotech (TOTAL)
- Algae supplied by US Department of Energy Contract DE-EE0003046 awarded to the National Alliance for Advanced Biofuels and Bioproducts (NAABB) program

Assumptions

- **Study is based on treating 32.5 lpm (8.6 gpm) of wastewater containing 20 ppm copper and a pH of 3.0**
- **Recovery of the copper bound to these resins can be achieved by backwashing with 10% by weight sulfuric acid**
- **Estimates assume copper removal requires approximately 6 cubic feet of resin with a design flow of 1.5 gallons per minute per cubic foot: bed depth of 1 meter**

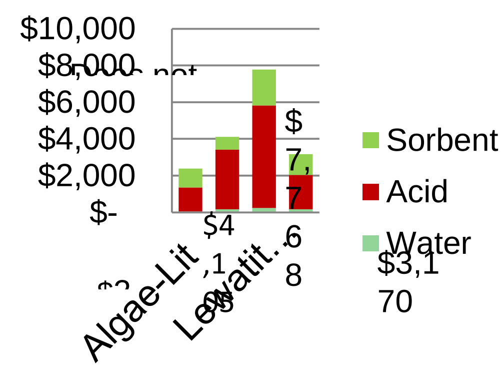
Annual Ion Exchange Treatment Costs

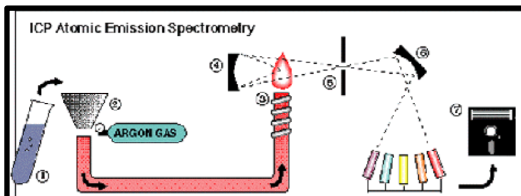


Standard Costs

Resin	S930	M4195	IRC748	TP 207	SIR 300
Supplier	Purolite	Dow	Rohm & Haas	Lewatit	Resintech
Bulk density, g/L	725	674	750	755	690
copper loading, g/l	35	39	43	35	35
Life, yrs	6	6	6	2	6
Cost, $/ft^3	345	3,494	630	325	380
Acid Rinse, BV	3.5	3	3	6	2
Water Rinse, BV	9	6	6	12	11

Comparison of Annual Treatment Costs Algae vs. Resin





Inductively Coupled Plasma (ICP)Process Cu(II) Detection Method

ICP Results

Sample	Cu Adsorbed, q (mg/g)
Algae 119-122	9.990
Algae 114-116	8.112
PurLite	9.941
Lewatit	9.945
ResinTech	9.947

Conclusion

- **Algae is a cost effective option to remove Cu(II) from CMP Waste**
- ***Chlorella sp.* is able to adsorb same quantity of Cu as resins**

Publications, Presentations, and Recognitions/Awards

Science Foundation Arizona Fellow 2008-2010 & NSF GK-12 Fellow 2010-2011

NSF-CMMI Research and Innovation Conference Grantee

Jones L, Ogden K. (2012). Silica & Titania Nanoparticles Impact on Water Quality: Experiments Involving Ralstonia pickettii in Nutrient Rich and Poor Media. Environmental Progress, in publication.

SRC/SEMATECH Engineering Research Center for Environmentally Benign Semiconductor Manufacturing

Tribological, Thermal, and Kinetic Attributes of 300 vs. 450 mm CMP

Senior Researchers:
- Ara Philipossian, Professor, PI
- Yun Zhuang, Postdoctoral Fellow
- Yasa Sampurno, Postdoctoral Fellow

Students
- Yubo Jiao, Xiaoyan Liao, and Changhong Wu, Ph. D. candidates, Chemical and Environmental Engineering, UA

Sponsored by:
- Intel
- Cabot Microelectronics
- Fujimi

Highlights:
We established 450-mm wafer processing capability and results showed that CMP consumable consumption can be reduced more than 20% through processing larger size (450 mm) wafers due to the associated higher material removal rate.

Aggressive Diamond Characterization and Wear Analysis during Chemical Mechanical Planarization

Senior Researchers:

- Ara Philipossian, Professor, PI
- Yun Zhuang, Postdoctoral Fellow
- Yasa Sampurno, Postdoctoral Fellow

Sponsored by:

- Cabot Microelectronics

Students

- Changhong Wu, Yubo Jiao, and Xiaoyan Liao, Ph. D. candidates, Chemical and Environmental Engineering, UA

In this project, we aimed to extend pad conditioner life by identifying its aggressive diamonds and investigating aggressive diamond wear evolution during chemical mechanical planarization.