Contactless Metal Electrodeposition for 3D Packaging Applications

PIs:

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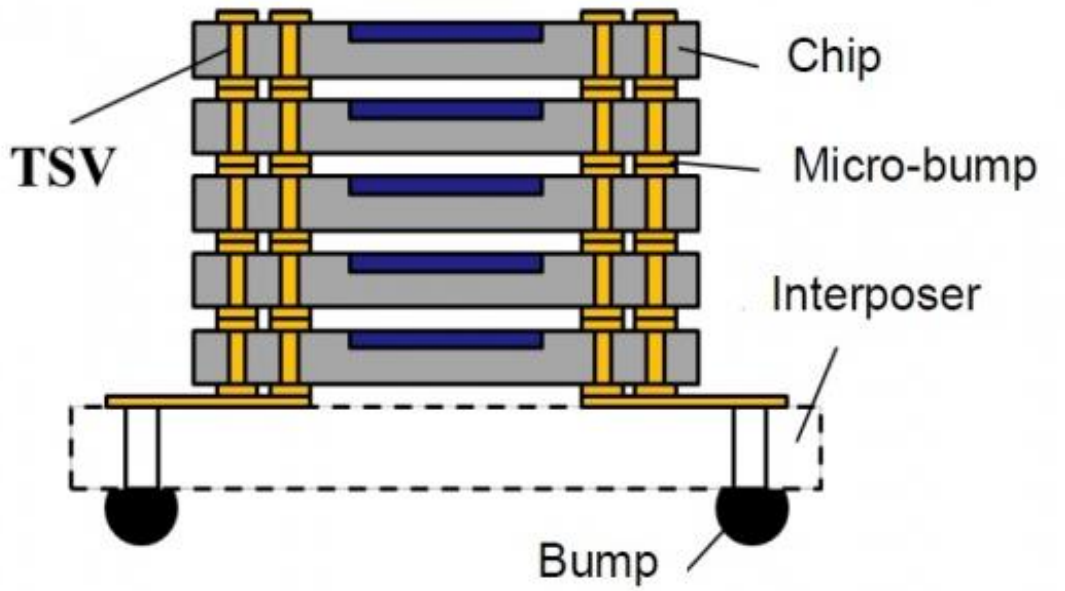
Industrial Mentors:

- **Steven Verhaverbeke, Applied Materials, Inc.**
- **Roman Gouk, Applied Materials, Inc.**

Cost Share (other than core ERC funding):

- **$50k from Applied Materials, Inc. (gift funds)**
- **$25k in-kind donation (reactor, wafers)**

Through Silicon Via (TSV) Technology

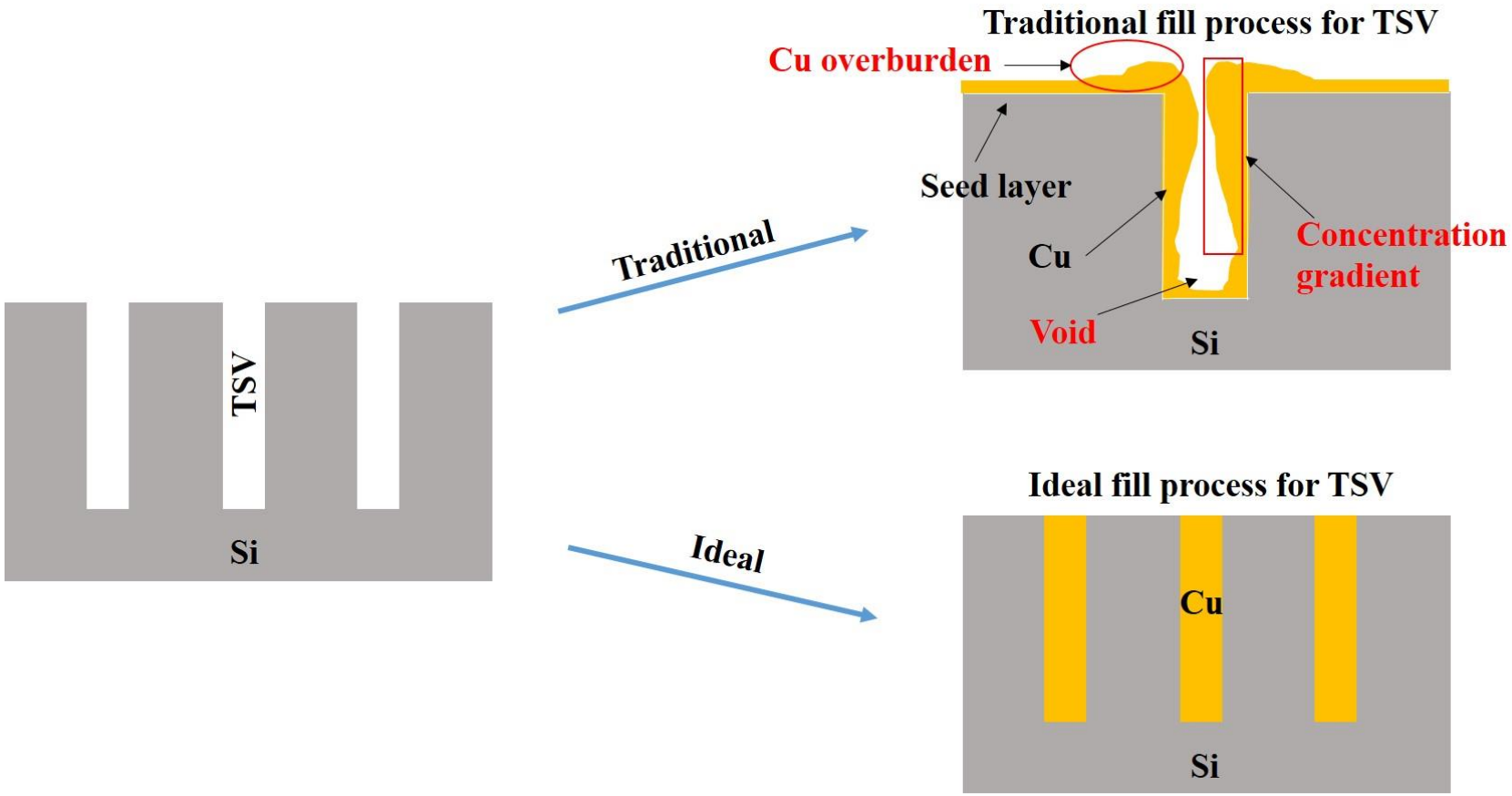


Model of stacked chips with TSV connections

- **TSV- key technology in 3D integrated circuit (IC) Packaging**
  - ***Shortest chip to chip interconnections***
  - ***Integration of different functional devices into one package***
  - ***High interconnection density, lower power and good reliability***

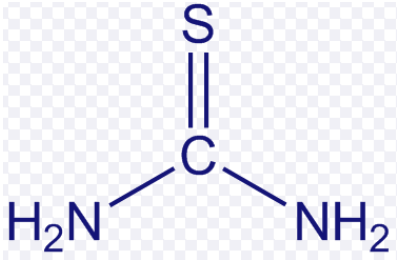
Figure source: ADEKA's additive for copper plating ideal for TSV, *Silicon Semiconductor Magazine*, 2013.

Challenges – Conventional Process



- *Filling of high aspect ratio vias (1-200 μm width, up to 20-50 aspect ratio) with Cu at high rates without formation of voids*
- *Keeping Cu overburden to a minimum to reduce CMP cost*

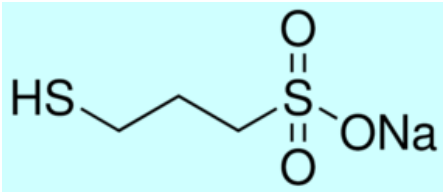
Commonly Used Additives - ESH and Process Impact



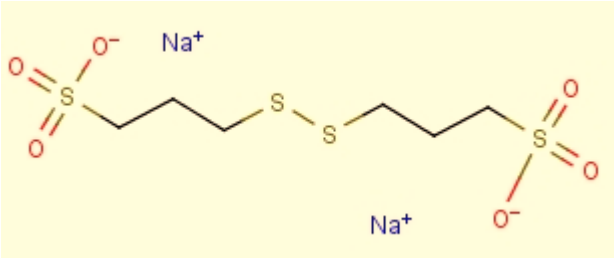
Leveler: Thiourea

- *Oral LD_{50} = 125 mg/kg (rat)*
- *health hazard rating of 3*
- *Toxic and suspected to cause cancer*

- *Subcutaneous LD_{50} = 1500 mg/kg (mouse)*
- *health hazard rating of 2*
- *Considered a hazardous substance according to OSHA.*



Accelerator:
3-Mercapto-1-propanesulfonic Acid Sodium Salt

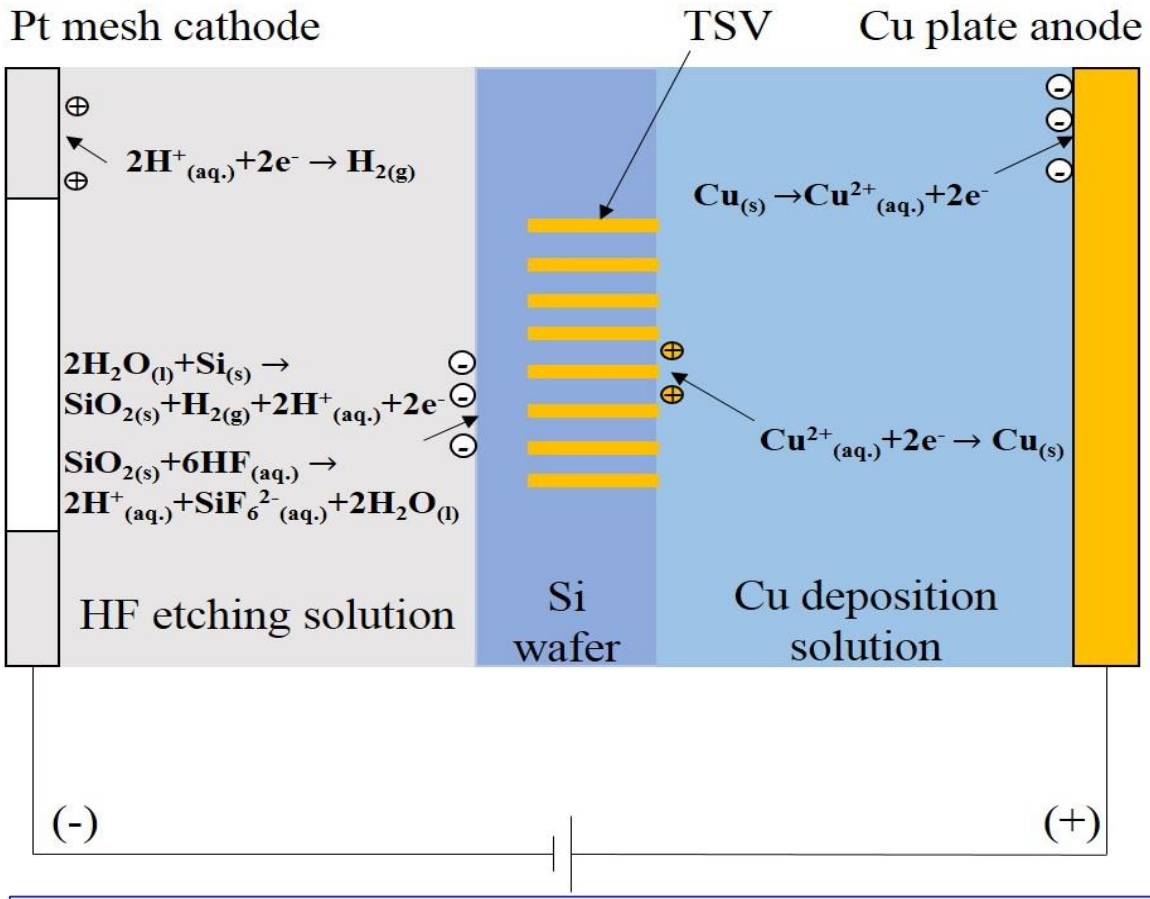


Accelerator: bis(sodiumsulfopropyl) disulfide

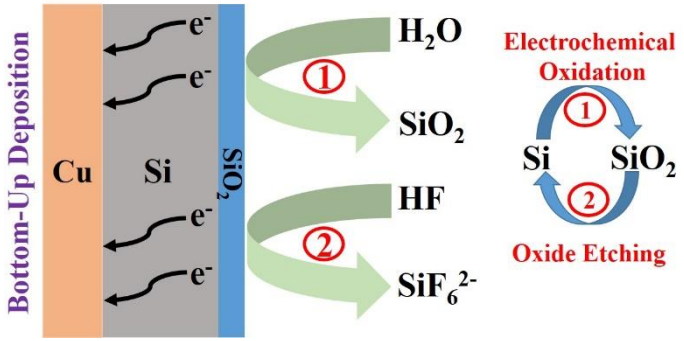
- *Oral LD_{50} = 300 mg/kg (mouse)*
- *Hazardous decomposition products at high temperature*

Additives may also reduce the quality and reliability of deposited metal when they get embedded in the metal

Proposed Contactless Electrodeposition Process



A bottom-up deposition approach w/o any additive.

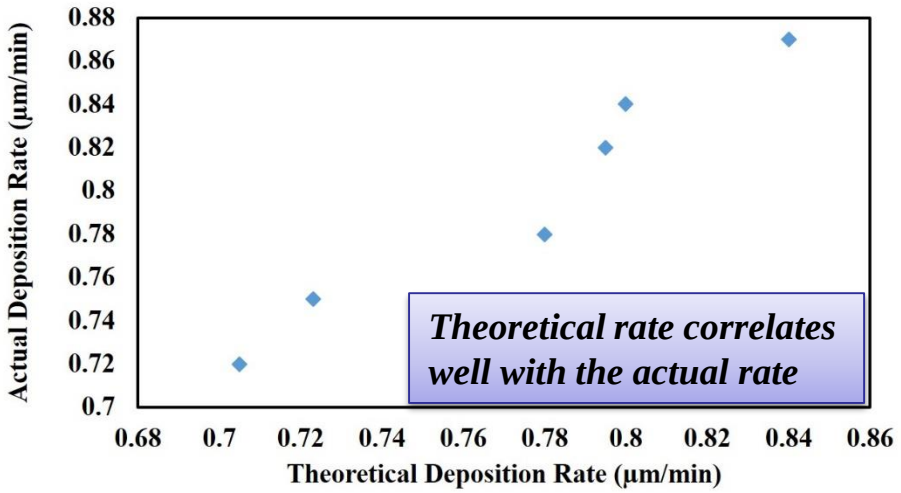


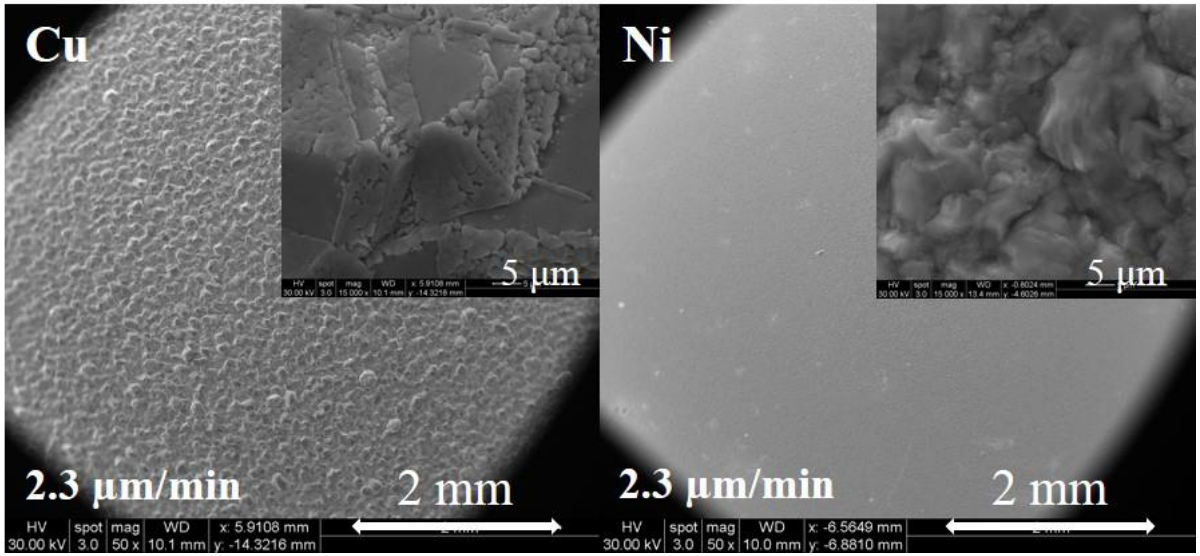
- ***Front side of wafer consisting of vias contacts with $CuSO_4$ – H_2SO_4 with Cu anode immersed in it.***
- ***The backside of wafer contacts SiO_2 etching solution with Pt cathode immersed in it.***

Economic and ESH Benefits of Contactless Process

- ***Bottom up approach leading to high metal deposition rate and excellent uniformity***
- ***Elimination of void or seam formation w/o additives***
- ***Minimization of CMP step and associated chemical usage, lower amount of waste and related disposal issues***
- ***Better monitoring and regulation of electrodepositon bath due to absence of additives***

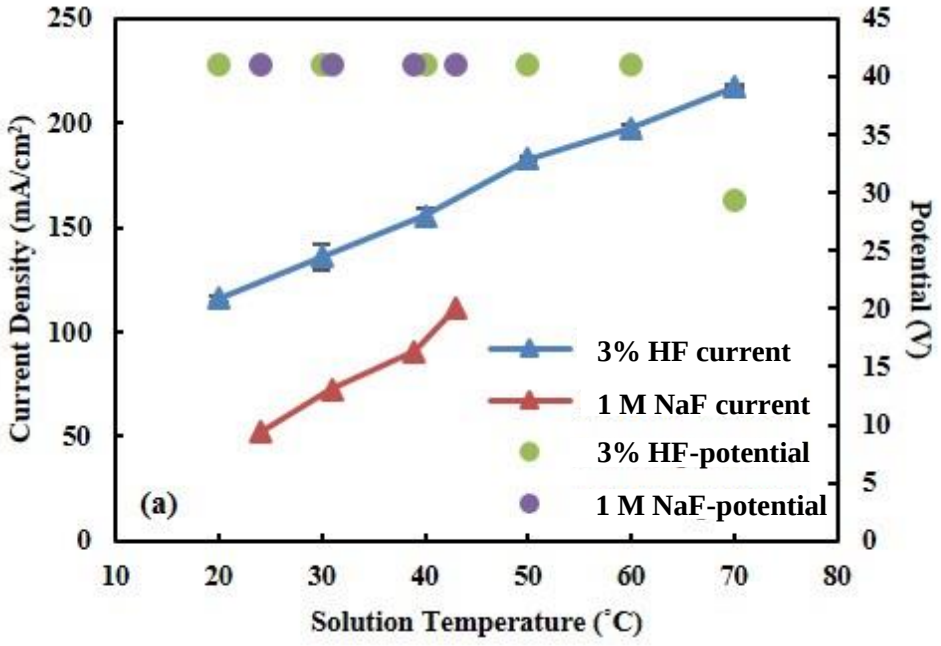
Feasibility Study

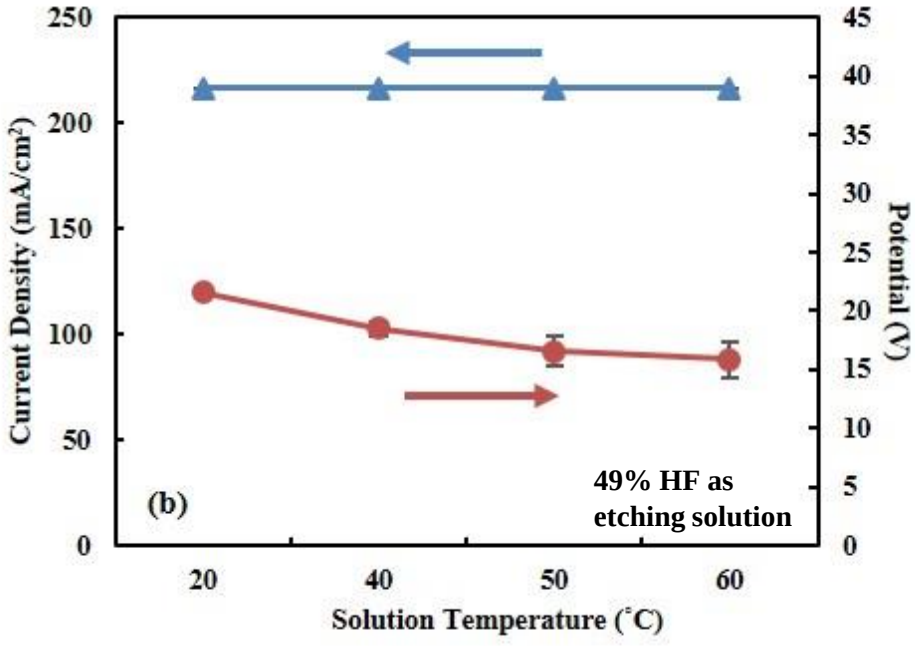




Compact and porosity-free films of electrodeposited Cu and Ni.

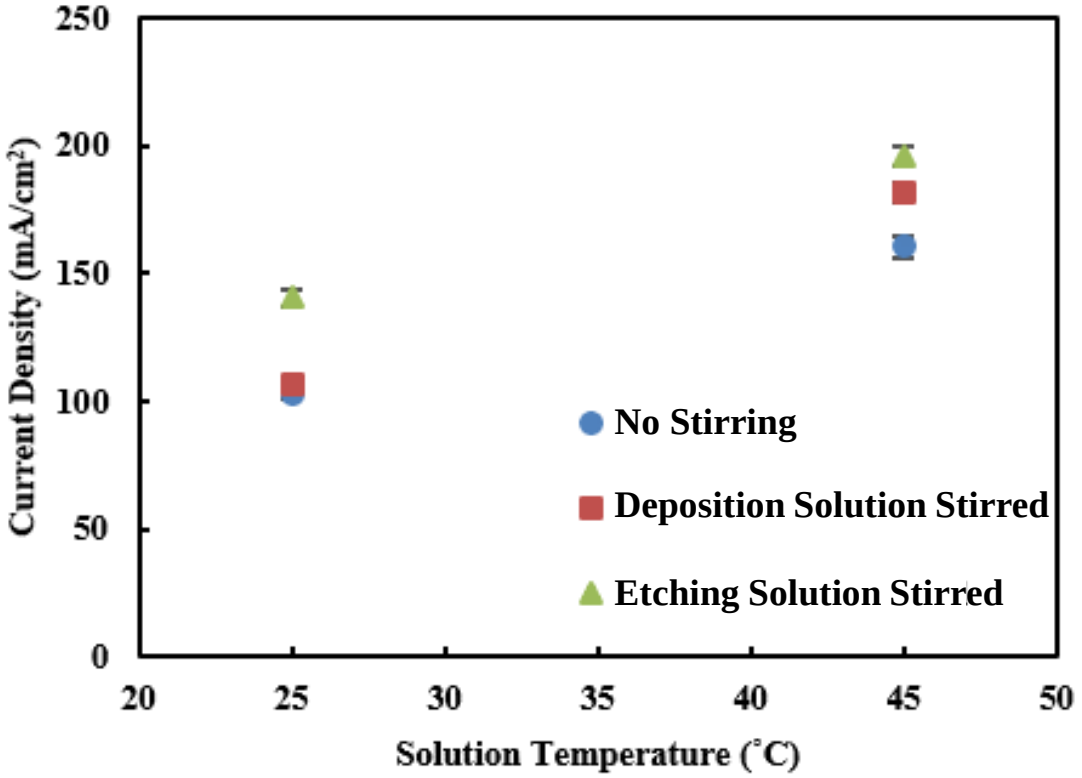
Effect of Solution Temperature and HF Concentration on Current Density (Ni Deposition)





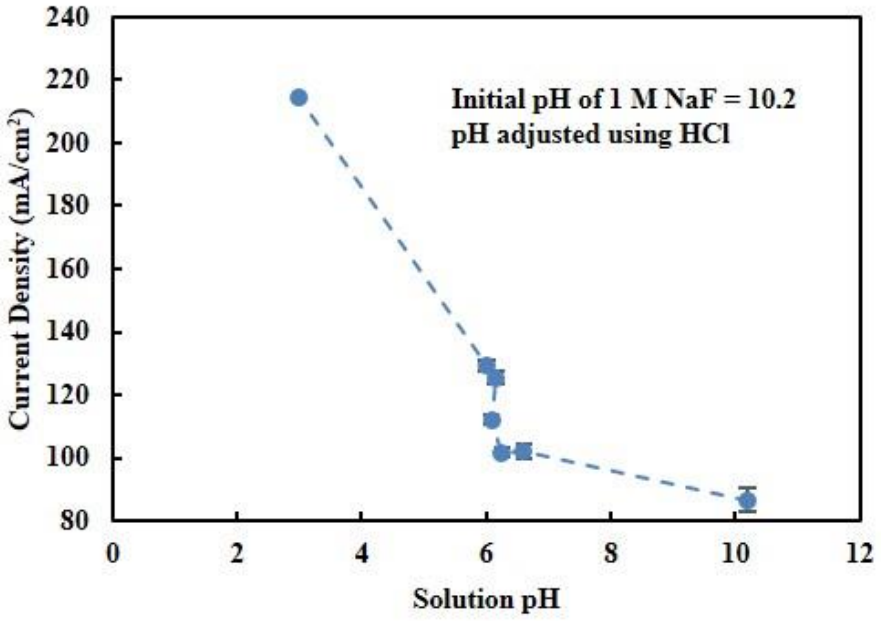
- ***Solutions with higher total F (49% HF) attained current densities as high as 220 mA/cm² at room temperature (20˚C), while a 3% HF solution exhibited only about 115 mA/cm²***
- ***Etching of silicon dioxide important in regenerating the silicon surface for achieving higher deposition rates.***

Effect of Stirring of Deposition/Etching Solution on Current Density (Ni Deposition)

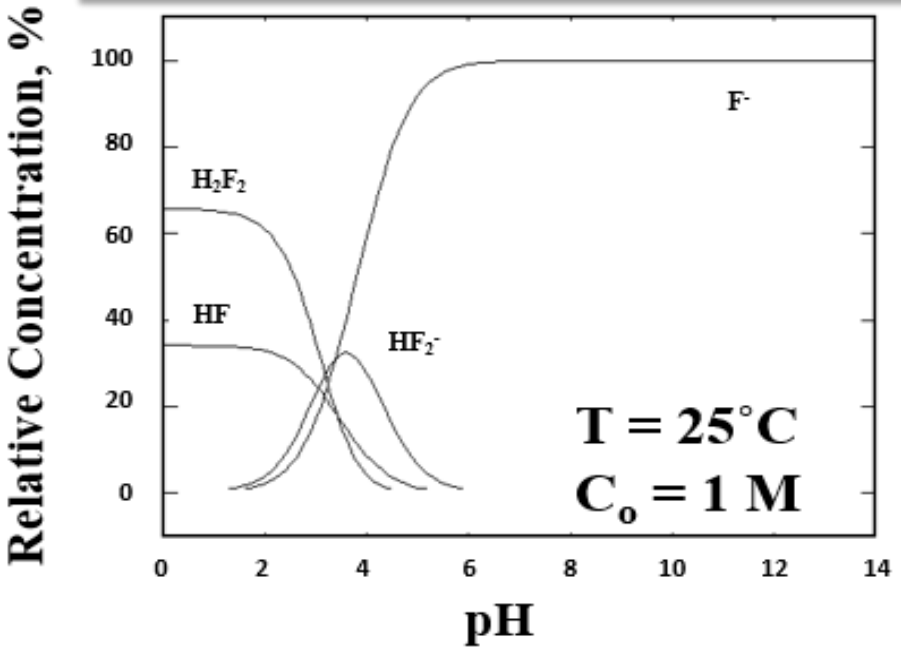


❖ *Oxidation and etching reactions more important than metal ion diffusion for achieving higher overall current density for deposition*

Effect of Etching Solution Composition on Current Density (Ni Deposition)



Constructed using equilibrium calculations



- ***NaF solution may be used as an alternative etching solution (instead of HF) in this process.***
- ***Below pH = 6, there is a rapid increase in current density, which reaches maximum at pH = 3 in the investigated pH range of 3-10.***

Summary and Future Work

- ***Summary***
  - ***Feasibility of contactless process demonstrated with high deposition rates and excellent uniformity w/o additives for blanket films***
- ***Future work***
  - ***Conduct studies on patterned wafers with vias of different sizes, aspect ratios and profiles***
  - ***Establish correlations between morphological, crystallographic, microstructural, chemical, and mechanical properties of the electrodeposited metal and process parameters***
  - ***Develop a process model for transport and deposition of metals***
  - ***Extend the use of technique to metals beyond copper and nickel***

Industrial Interactions and Publications

- **Industrial Interactions**
  - ***Regular (monthly) discussion meetings with Applied Materials, Inc.***
  - ***Feedback provided by Dr. Steven Verhaverbeke and Dr. Roman Gouk (Applied Materials, Inc.) on industry process requirements and new trends***

- **Publications**
  - Z. Patterson, C. Weber, R. Balachandran, R. Gouk, S. Verhaverbeke and M. Keswani, A Technique for Contactless Copper Electrodeposition for 3D Packaging Applications, *ECS Electrochem. Lett.*, **3** (10), D41-43 (2014).
  - C. Weber, Z. Patterson, M. Zhao, R. Balachandran, R. Gouk, S. Verhaverbeke, F. Shadman and M. Keswani, Investigations of Solution Variables in a Contactless Copper Electrodeposition Process for 3D Packaging Applications, *Mater. Sci. Semicond. Process.*, **30**, 578-584 (2015).
  - M. Zhao, R. Balachandran, Z. Patterson, R. Gouk, S. Verhaverbeke, F. Shadman and M. Keswani, Contactless Bottom-Up Electrodeposition of Nickel for 3D Integrated Circuits, Under Review in *RSC Advances* (2015)