NXP | FTF 2016 TECHNOLOGY FORUM

BATCH AND STRIP-TYPE PLASMA CLEANING CONFIGURATIONS

FTF-INS-N2010

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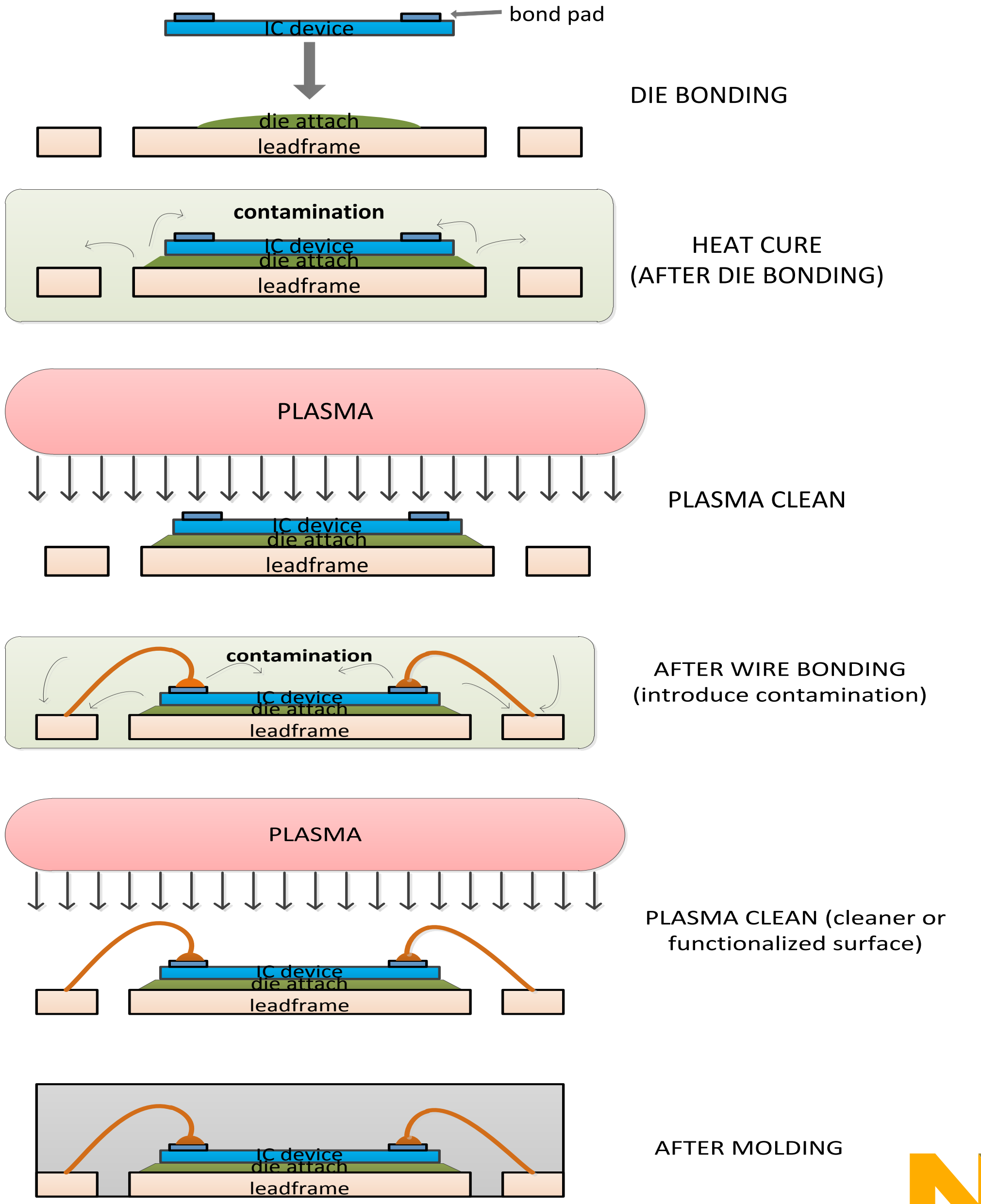
AGENDA

- 1.0 Introduction
- 2.0 Fundamentals
- 3.0 Plasma Sources and Configurations
- 4.0 Applications and Case Studies
- 5.0 Summary and Conclusion
- 6.0 Next Steps and Recommendations

1.0 INTRODUCTION

Motivations

- In IC packaging, it is important to maintain the cleanliness of the surface (e.g. substrate, leadframe, bond pads) during processes
- In die bonding, heat curing induces contamination on bond pads (through outgassing)
- Plasma cleaning is introduced before wire bond to clean bond pads and improve bondability
- Plasma cleaning is introduced before molding to improve surface wettability and delamination
- ***But how will the plasma clean impact on the reliability of copper wire bond packages?***

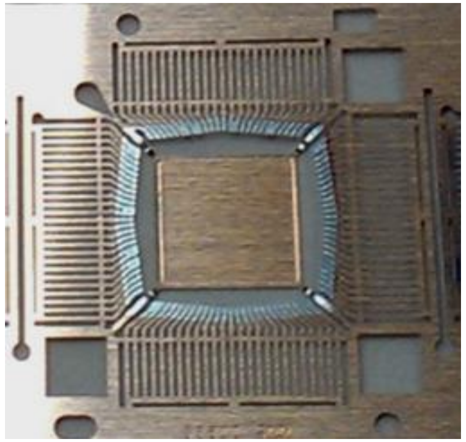


Basic Requirements in Plasma Cleaning Systems

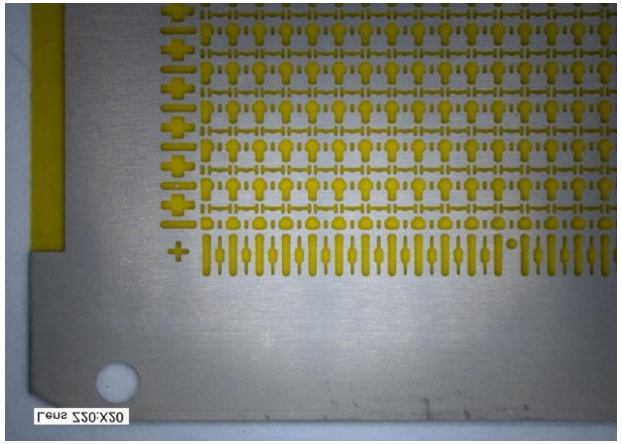
- Compatible to high volume manufacturing
  - Be able to process many strips in batches or process strips continuously
- Simple and efficient process
  - Procedure is easy to follow by operators, parameters controllable/repeatable
- Be able to monitor the process and equipment performance
  - Effectiveness can be measured/monitored (e.g. contact angle as process response) and equipment robust
- Used to improve processability and package integrity
  - Process should be able to provide improvements (improved wire bondability, delamination, and package performance)
- ***This presentation will provide some insights on plasma cleaning applications in IC packaging, covering both IC and small discrete packages***

Plasma Cleaning for IC and Discrete Packages

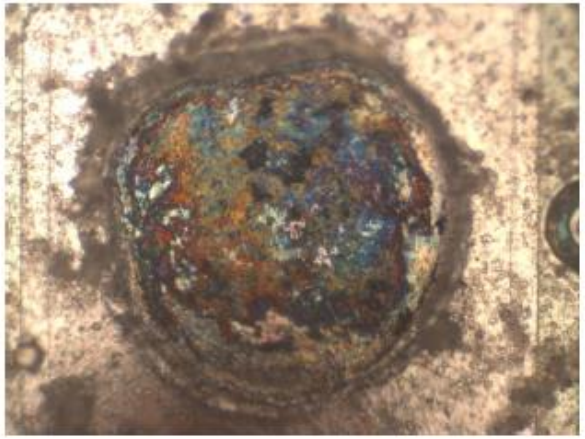
- Challenges for IC and discrete semiconductor packages
  - Better wire bondability and improved package integrity
  - Can be improved by cleaner bond pad prior to wire bonding thus plasma cleaning
- Focus of this presentation
  - Plasma cleaning for Cu wire bonded packages
  - Cleanliness of the bondpad (e.g. Aluminum) is more critical in Cu wires (than Au) due to corrosion. Corrosion also reported for Ag wires.



IC Package Leadframe (HLQFP100)



Discrete Package Leadframe (SOD882)



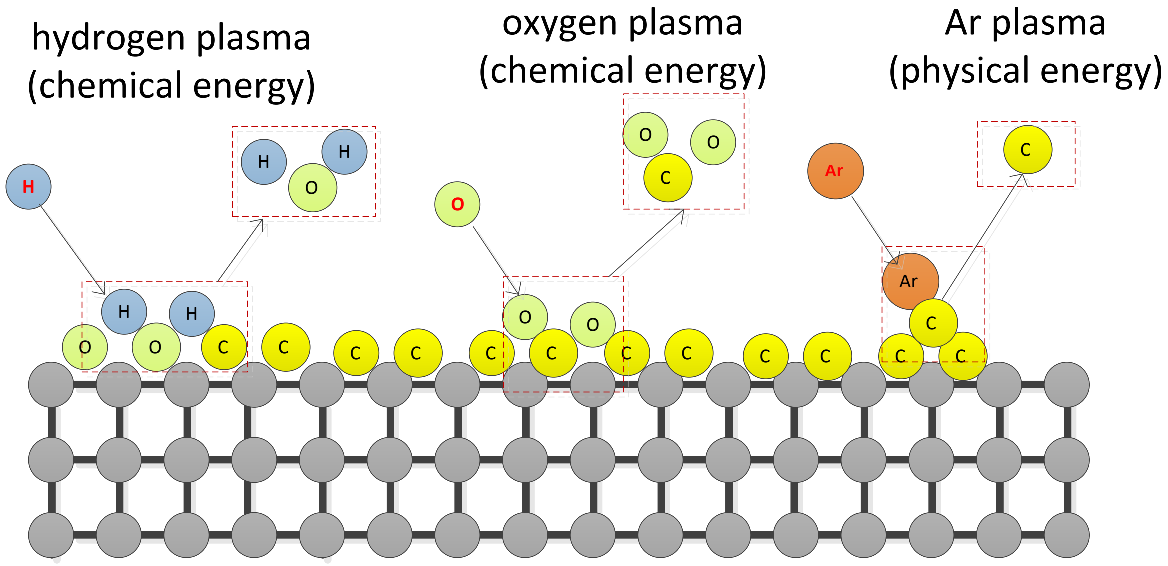
IMC Corrosion in Cu Wire on Al Bond Pad

IMC Corrosion in Ag Wire on Al Bond Pad

2.0 FUNDAMENTALS

Plasma Generation

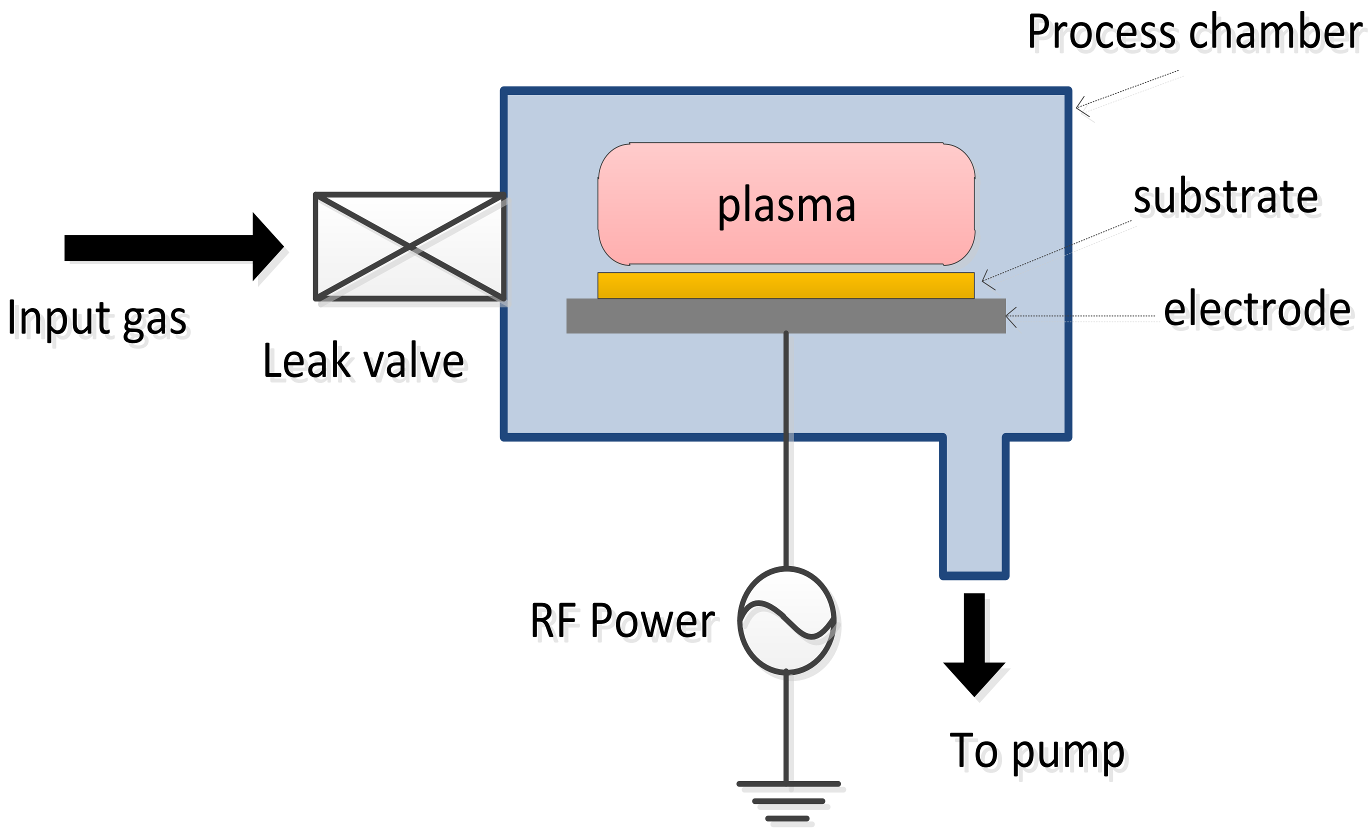
- Plasma discharge
  - Neutral gas converted to ionized gas (reactive species)
  - Generation of photons, hot electrons, energetic ions, neutral species
- Different species interact with the surface
  - Removal of atoms by chemical or physical sputtering
  - Surface functionalization and surface heating



- *Electrons*: light → fast → electric field (ionization)
- *Ions*: heavy → slow → electric field (physical bombardment
- *Neutrals atoms* : heavy → slow → neutrals (chemical reaction)

Basic Procedure in Plasma Cleaning

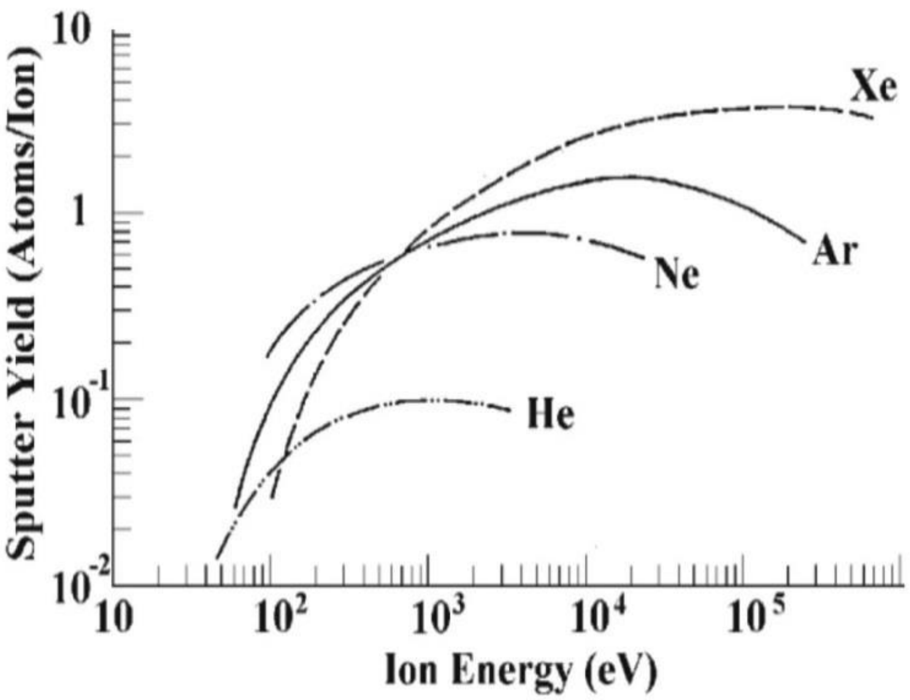
- Introduce gas in the vacuum chamber (leak valves/MFC)
- Power the electrode (RF, DC, microwave)
- Generate plasma
  - Neutral gas is energized
  - Plasma is generated
  - Forms a sheath near the substrate/leadframe surface
  - Species interact with the surface



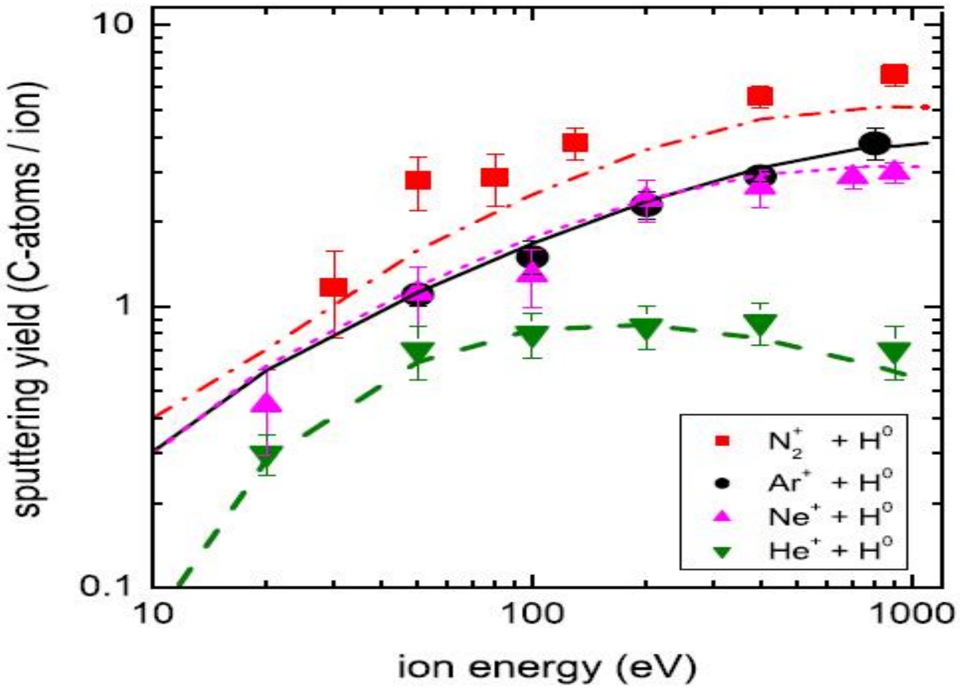
Important Plasma Parameters

- Pressure
  - At higher pressure, increase in reactive species and more neutrals produced. For neutrals, primary mechanism is chemical etching. Overall, lower average ion energies.
  - At lower pressure, ion bombardment is dominant (e.g. sputtering). Increase in electron temperature, increase in DC bias. Anisotropic removal of the surface.
- Power
  - Linear, more cleaning at increased power
- Time
  - Linear, more cleaning at longer period

Effect of Gases on Sputtering Yield/Rate



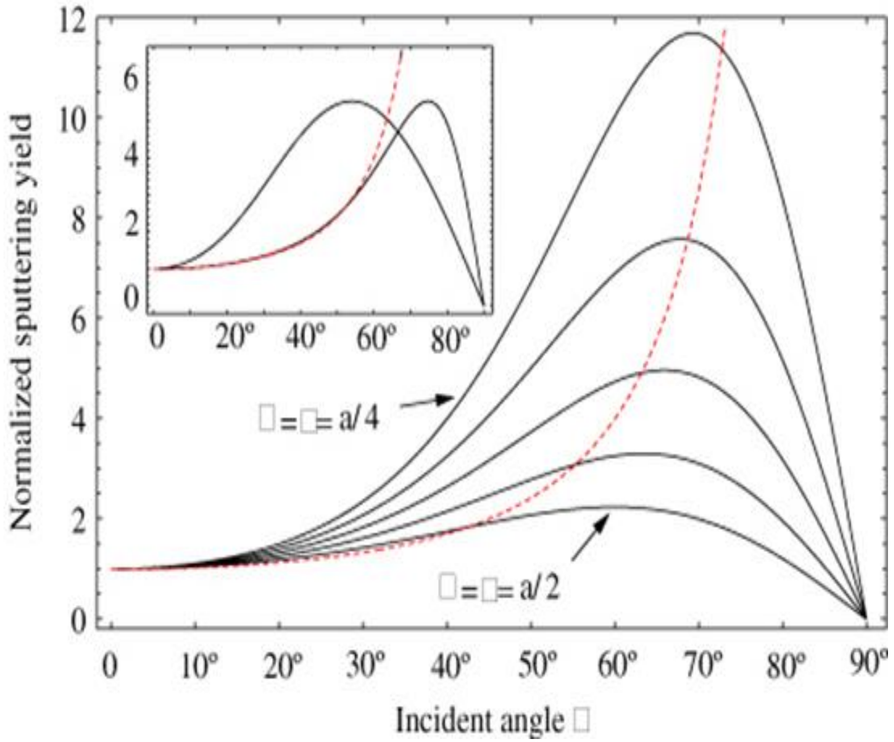
Sample Sputter yields of silicon as a function of ion energy for noble gas ions at normal incidence (Si target)

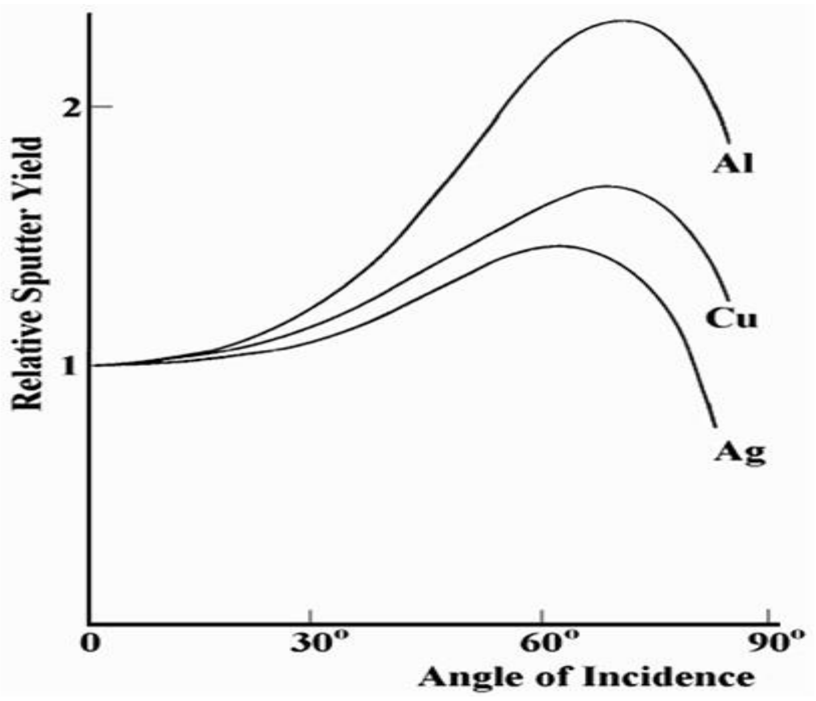


Chemical removal of particles on a surface (can approximate chemical erosion yield as a function of energy)

Ref: Thermo-Fisher Scientific 2013

Sputtering Yield (Function of Material and Angle of Incidence)





The variation of the sputter yield with angle for the three metals. At around below 60º, the sputter rate increases with angle before passing through a maximum.

Ref: Qiangmin Wei, Kun-Dar Li, Jie Lian and Lumin Wang , **Angular dependence of sputtering yield of amorphous and polycrystalline materials**, J. Phys. D: Appl. Phys.**41**No.17 (7 September 2008)172002(4pp)

Ref: M Schlüter, C Hopf and W Jacob, **Chemical sputtering of carbon by combined exposure to nitrogen ions and atomic hydrogen.** New J. Phys. **10** (2008) 053037

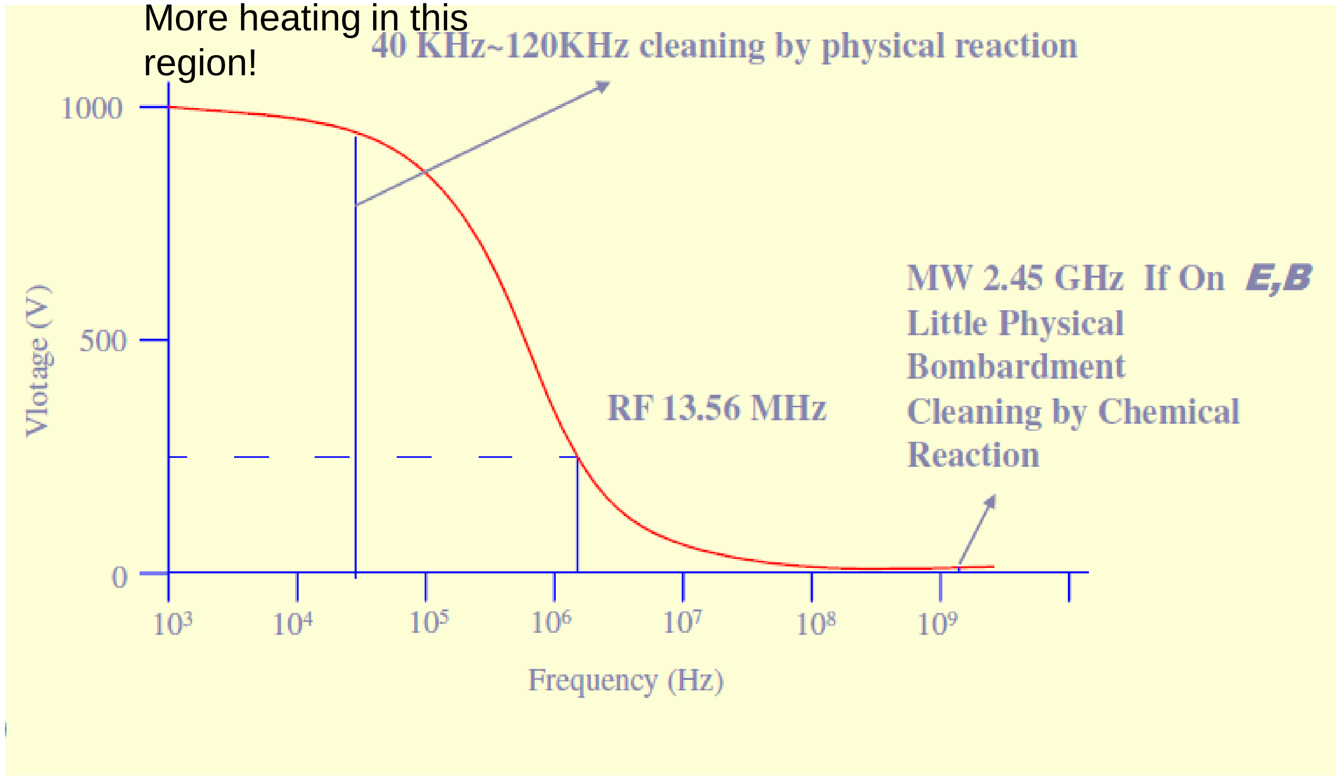
Chapter 2 Summary

- Discussed how plasma is generated
- Discussed how plasma interacts with the surface
- Discussed how to make use of plasma for cleaning surfaces and the basic procedures involved
- Introduce some of important parameters to control in the plasma cleaning process
- Effect of gases in the cleaning rate (through the sputtering yield concept)
- Introduction of the sputtering yield as a function of material and angle of incidence (which is important in understanding the basic configuration in the design of a workable plasma cleaning system)

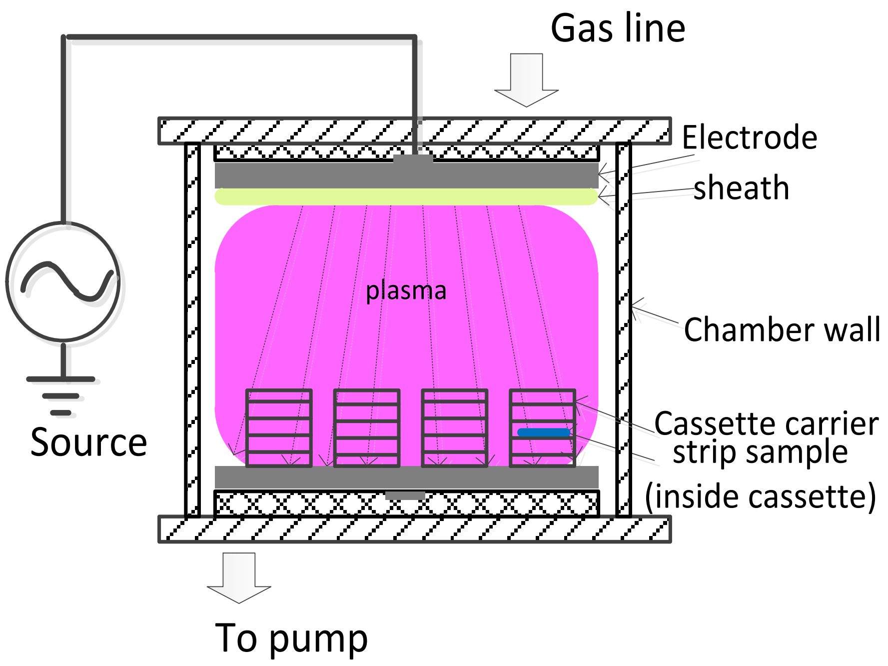
3.0 PLASMA SOURCES AND CONFIGURATIONS

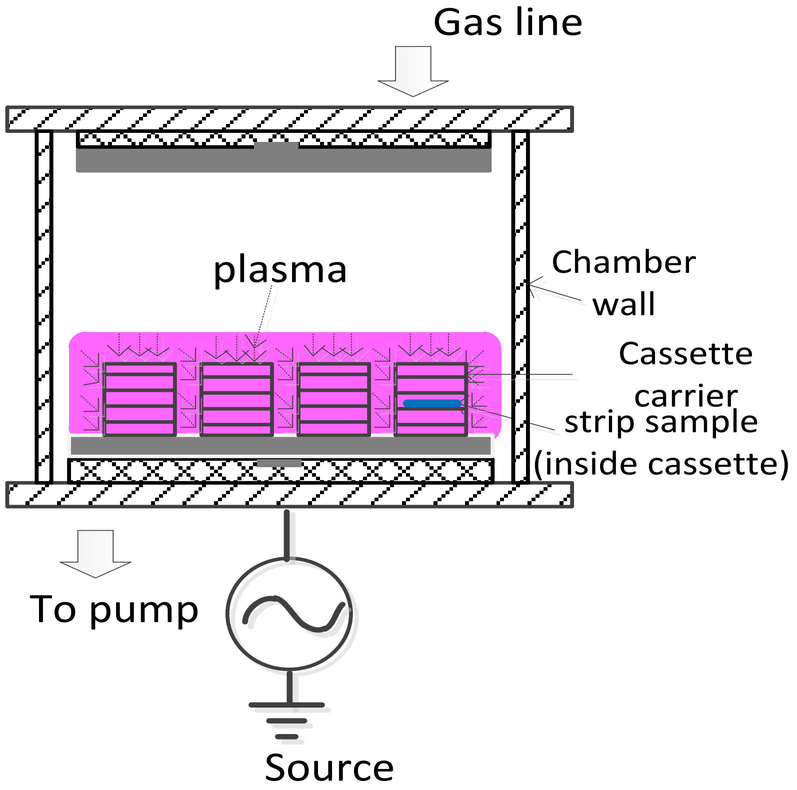
Plasma Sources

- Different plasma sources (direct current or DC, microwave, electron cyclotron resonance or ECR, radio frequency RF, etc.)
  - Plasmas is generated by applying an electric field on electrode/s
- In DC plasma, a constant electric field is applied
- In RF plasma, an alternating electric field is applied
  - At sufficiently high frequency, electrons oscillate, colliding with gas molecules to generate ions
- In many standards plasma cleaning systems, RF plasma is used



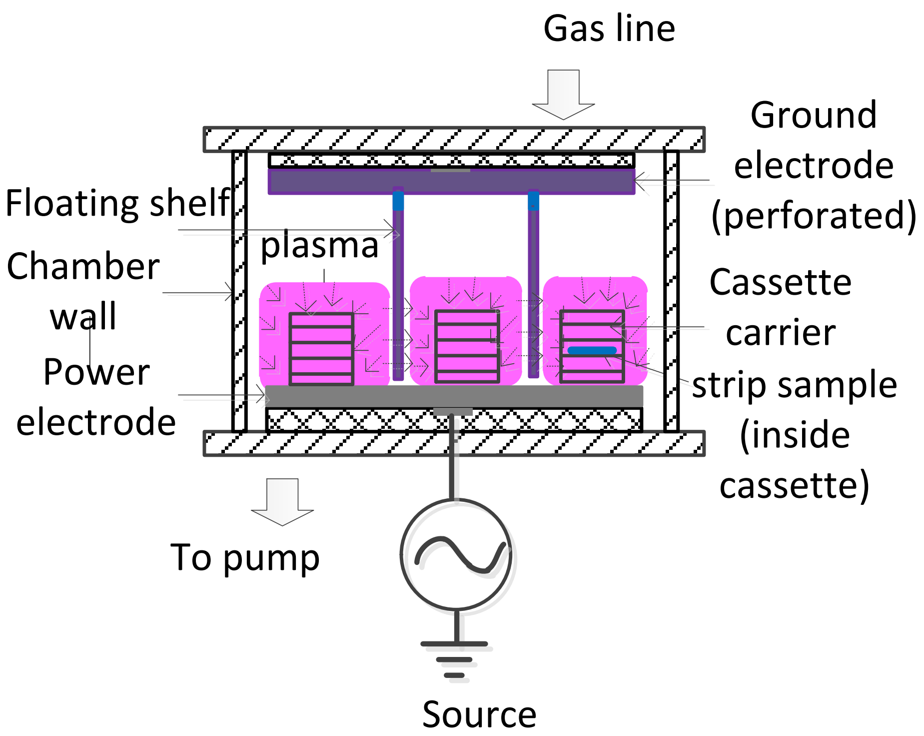
Batch Plasma – Parallel Plate Configuration

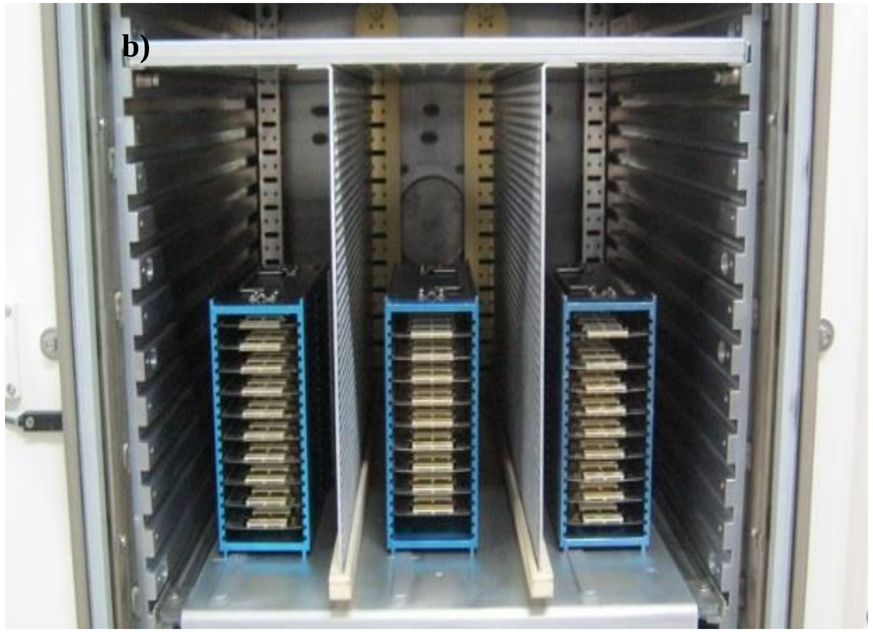




- Conventional batch-type plasma cleaning
  - Earliest types of plasma cleaners used in IC package assembly
  - Allows magazines to be loaded at a time onto a slot that serves as either the ground (indirect) or power electrode (i.e. direct or reactive mode)

Batch Plasma – Floating Shelf Configuration

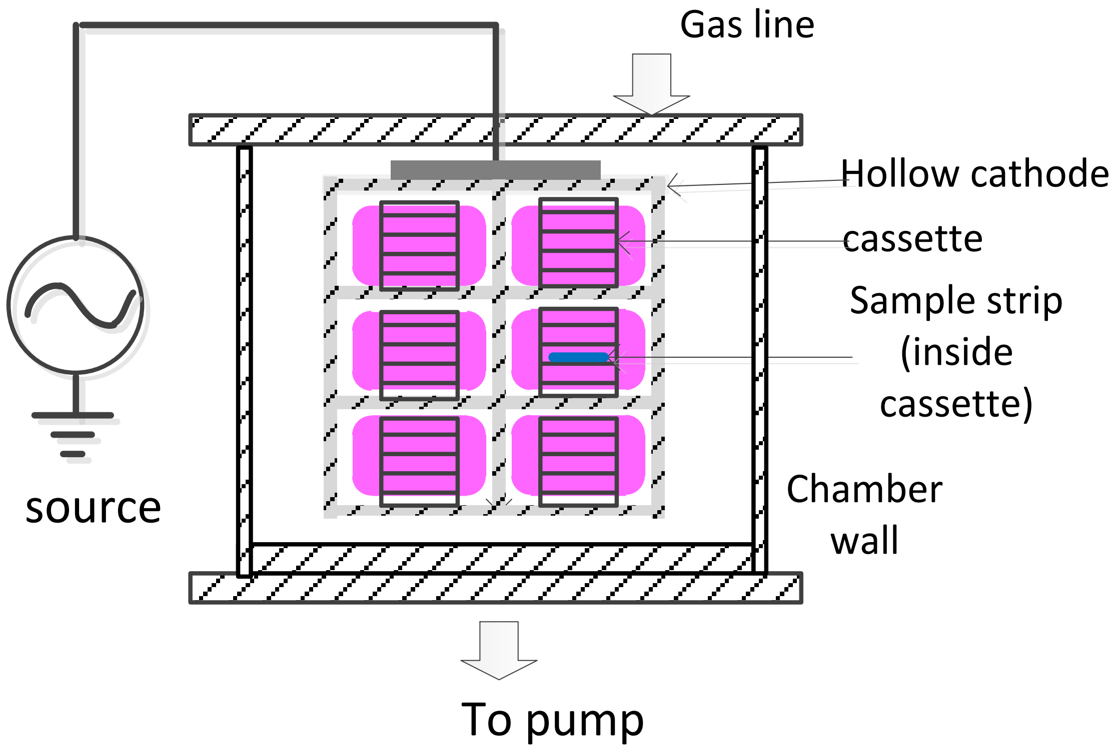




- This configuration works in direct mode while the floating shelf acts as separator between cassettes.

- Taller cassettes can be used.
- Plasma is generated and confined on each shelf/cassette carrier

Batch Plasma – Hollow Cathode Configuration



- The power electrode is connected to a compartment (i.e. hollow cathode) where the cassette carriers are placed
- Plasma is generated along the sidewall areas of the powered electrode

Pros and Cons in a Batch Plasma System Configuration

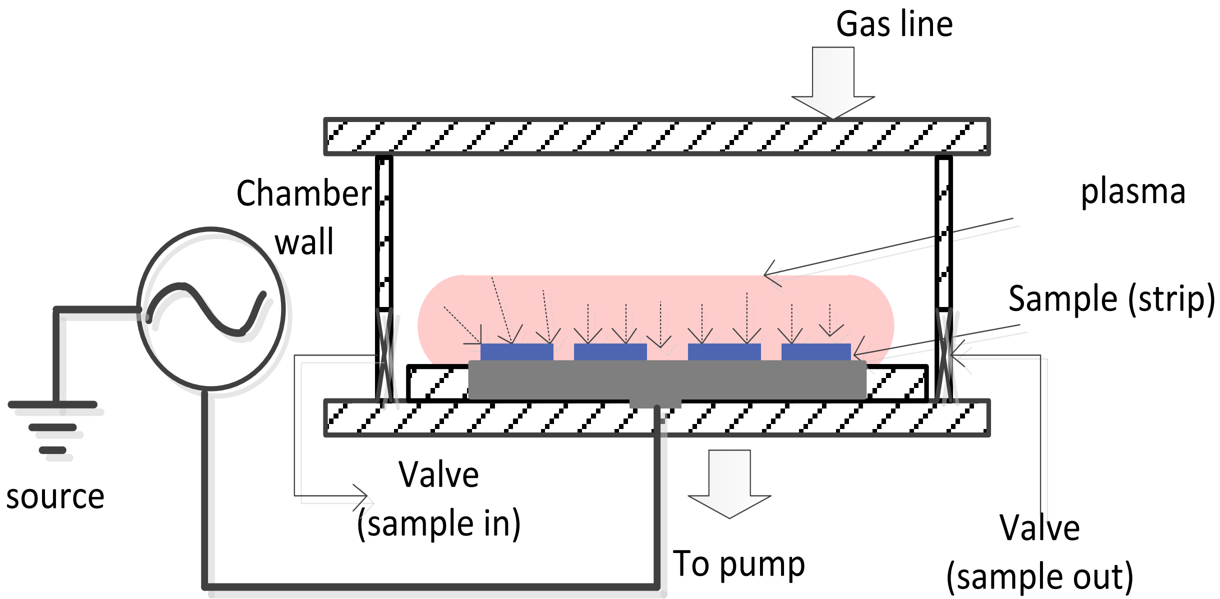
Pros

- High throughput
- Robust system (no automation/moving parts)

Cons

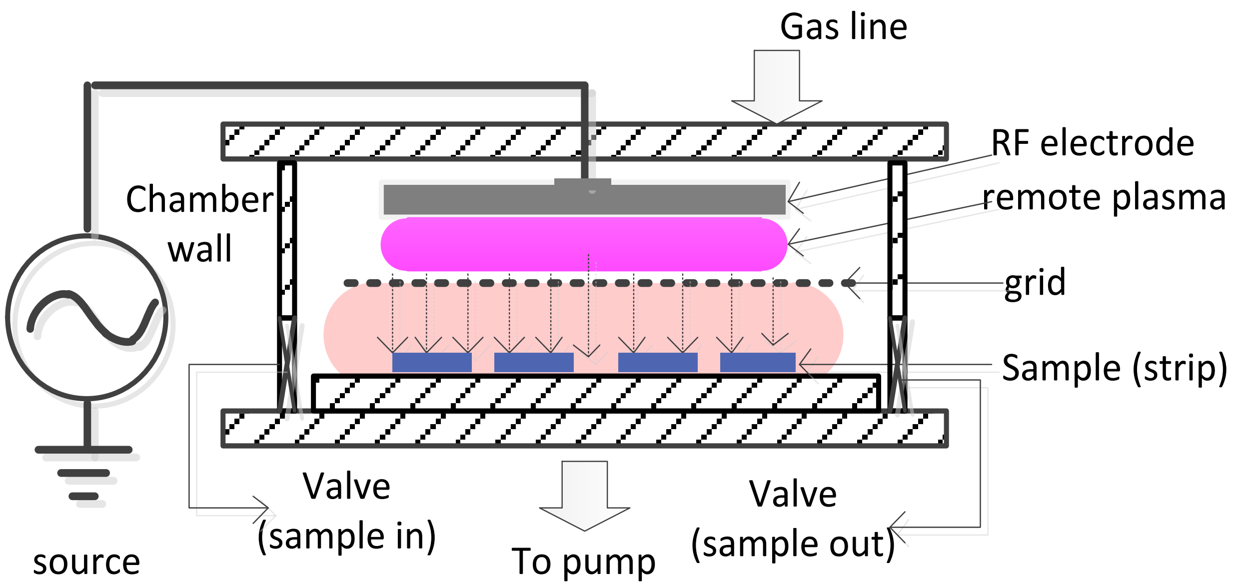
  - Staging of cleaned samples prior to next process
  - Cassettes/magazines are cleaned inside the chamber
- Poor uniformity (depends on the chamber and electrode configuration)
- Susceptible for recontamination (large surface area of electrode/cassette and the sample area)

Strip-to-strip (sts) Plasma – Direct Mode Configuration



- Sample strips are carried to the plasma chamber at a time
- Fast pumping and process time (smaller reaction chamber, reduced treatment time)
- Must continuously process strips to allow comparable throughput with that of the batch systems

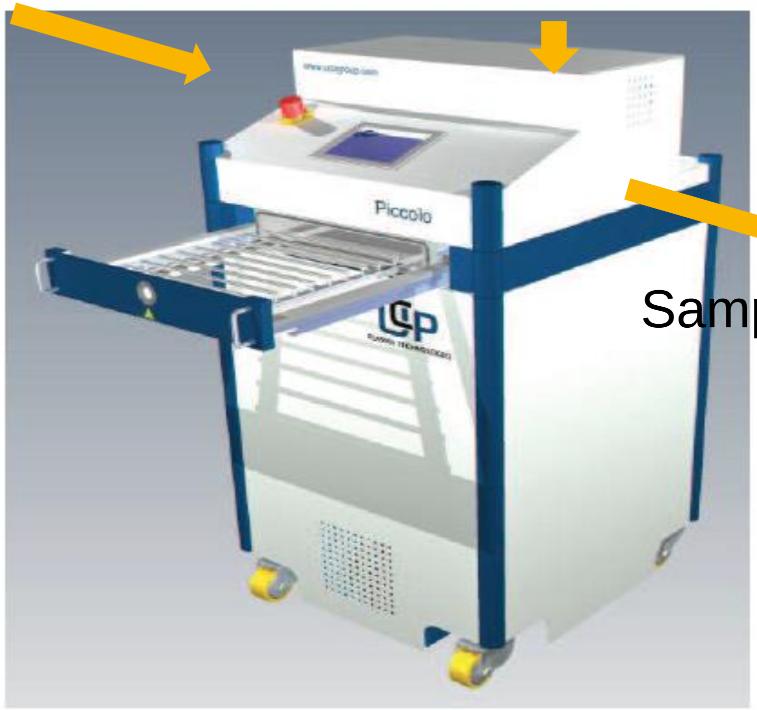
Strip-to-strip Plasma – Indirect Remote Configuration



- Use indirect plasma where reactive species (ions, neutrals) are generated outside of the sample area
- No heating of samples
- No sputtering thus no redeposition

Samples in

Separate Plasma source (with grid)

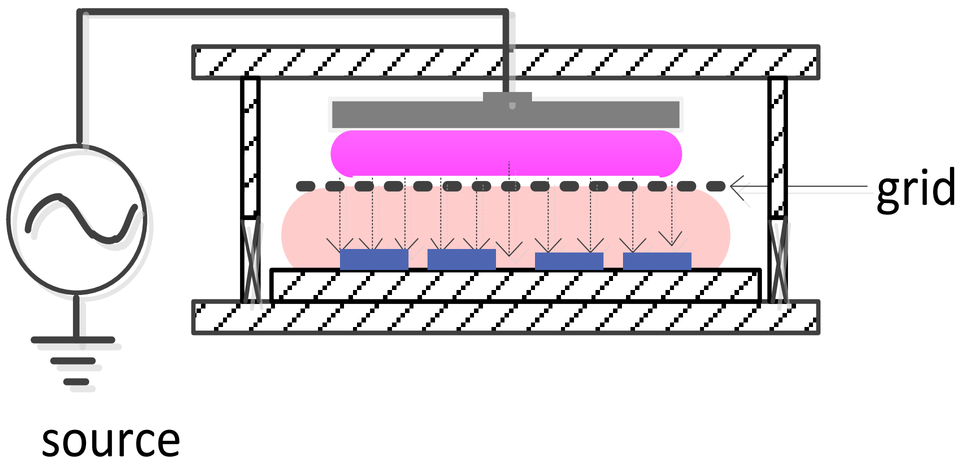


Samples out

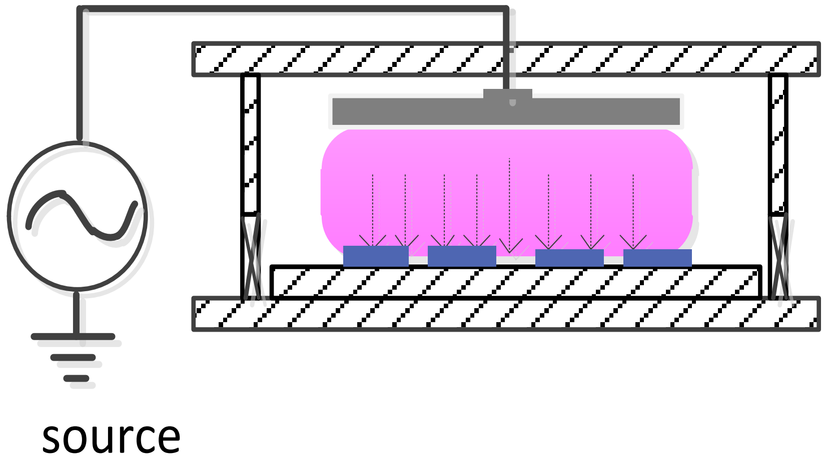
- Stand-alone system but can be retrofitted with automation for continuous operation

Comparison of Direct vs Indirect Strip-to-strip Plasma

- Indirect
  - Uses remote plasma source
  - Strip samples are in separated chambers.
  - Avoids physical cleaning effects such as heating, ion bombardment, redeposition



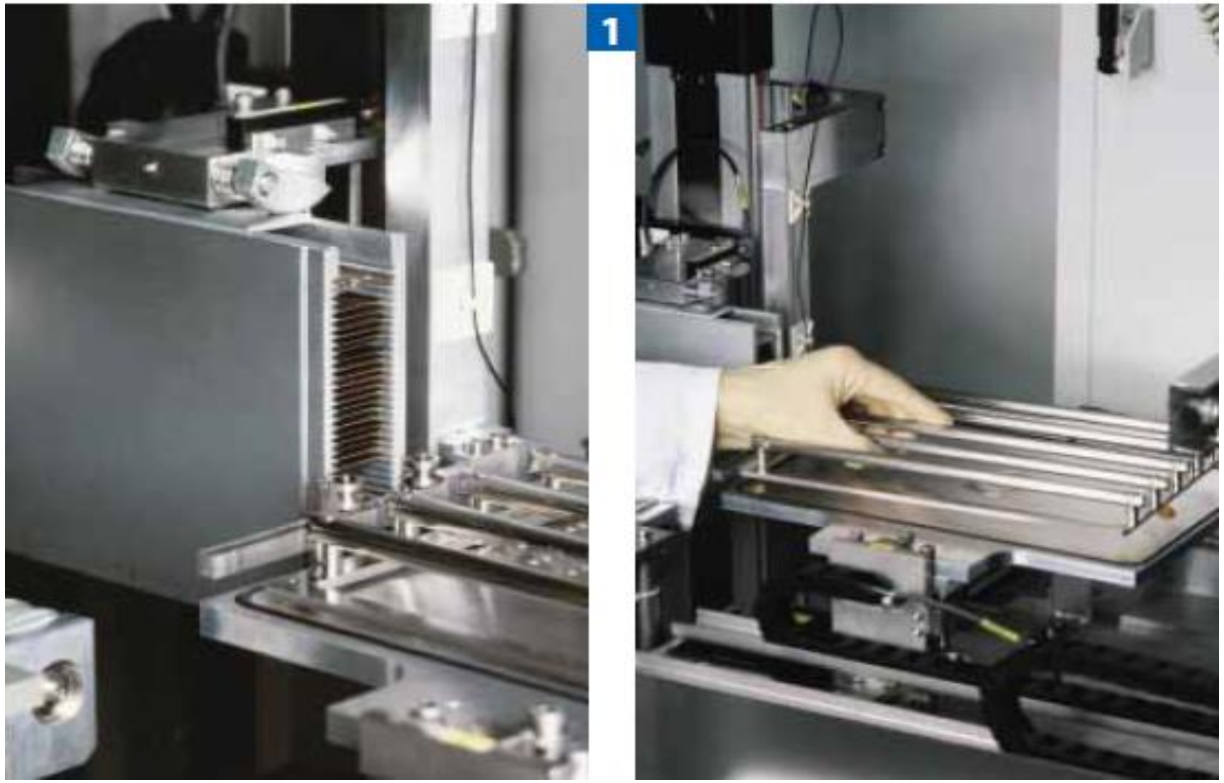
- Direct plasma
  - Sample strips and the plasma source are in the same chamber
  - Combination of chemical and physical sputtering for cleaning
  - Heating and redeposition cannot be avoided



Pros and Cons in a Strip-to-strip Plasma System

Pros

- Strips are loaded/unloaded directly onto the chamber (no cassette transfers, less handling)
- Short treatment/plasma exposure time (favorable for sensitive devices)
- Backside of the strip is not exposed to the plasma (favorable for a LF with tape)



Cons

- Only a few strips can be processed at the same time
- Loading/unloading system to compensate for UPH (moving parts, frequent pumpdown)

Gas System Requirements (Batch and sts Plasma)

Batch plasma systems

- Can use pure (N_2 or Ar) or mixed gas (e.g. Ar-H_2 95%-5% ratio)

Strip-to-strip (sts) Plasma system (Direct Mode)

- Can use pure (N_2 or Ar) or mixed gas (e.g. Ar-H_2 95%-5% ratio)

Strip-to-strip (sts) Plasma system (Indirect Mode)

- Step processing using N_2 and Ar-H_2 (95%-5%) mixed gas

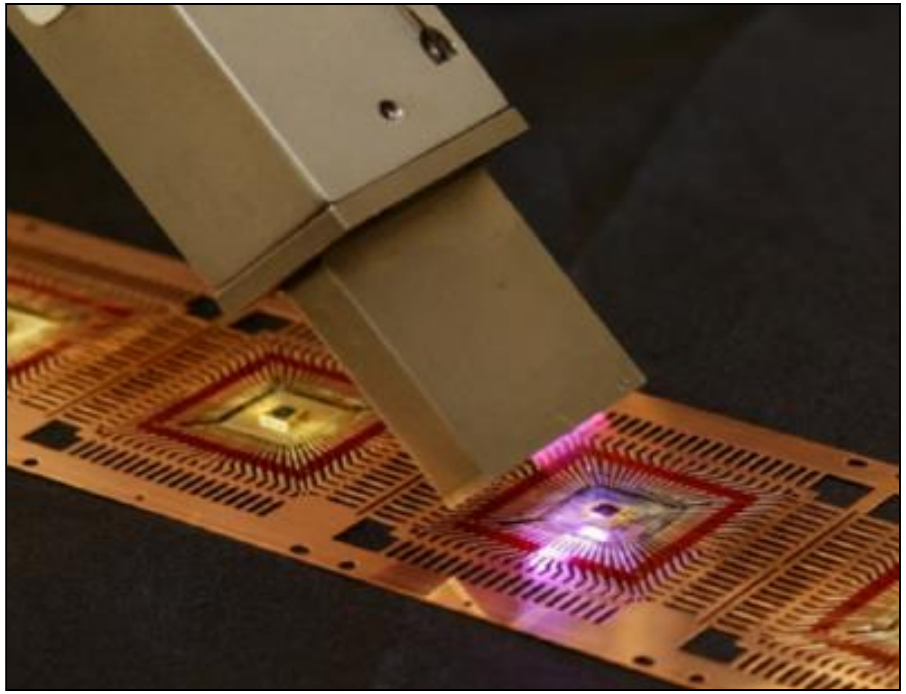
Batch Plasma System

Strip-to-strip (Direct Mode)

Strip-to-strip (Direct Mode)

Plasma for Autolines

- Vacuum system requirements in plasma systems
  - Most plasma cleaning systems use vacuum
  - Operation is at low pressure and low temperature
- NXP which employs both batch and sts systems use vacuum chambers
- System requirements for autolines
  - Difficulty in implementing vacuum system with autoline
  - Atmospheric plasmas can be used (e.g. atmospheric microwave plasma)
  - Challenge is how to compensate for the fast reel movement, treatment time on matrix leadframe



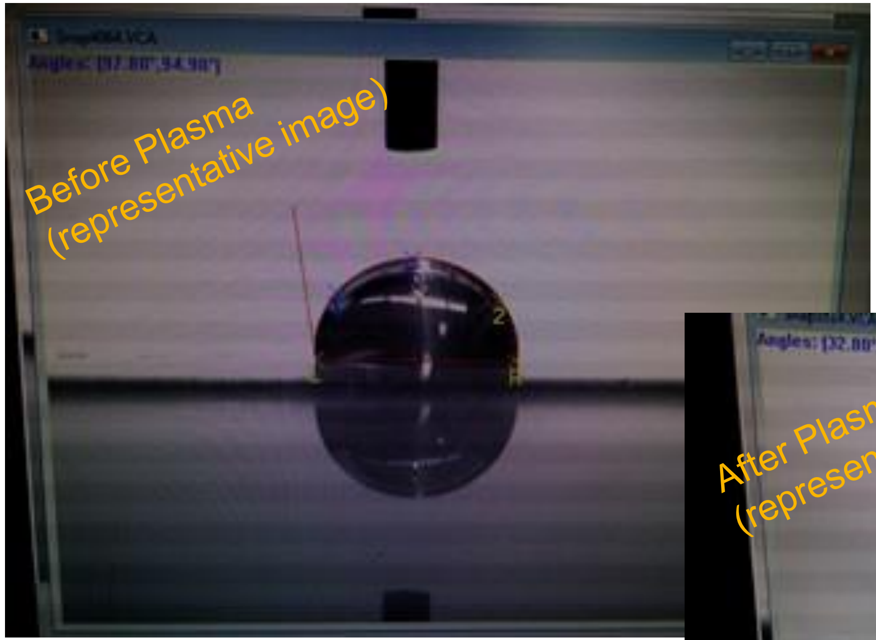
Single electrode atmospheric plasma cleaning from Surfx's AtomFlo™

4.0 APPLICATIONS AND CASE STUDIES

4.1 PLASMA RESPONSE: CONTACT ANGLE

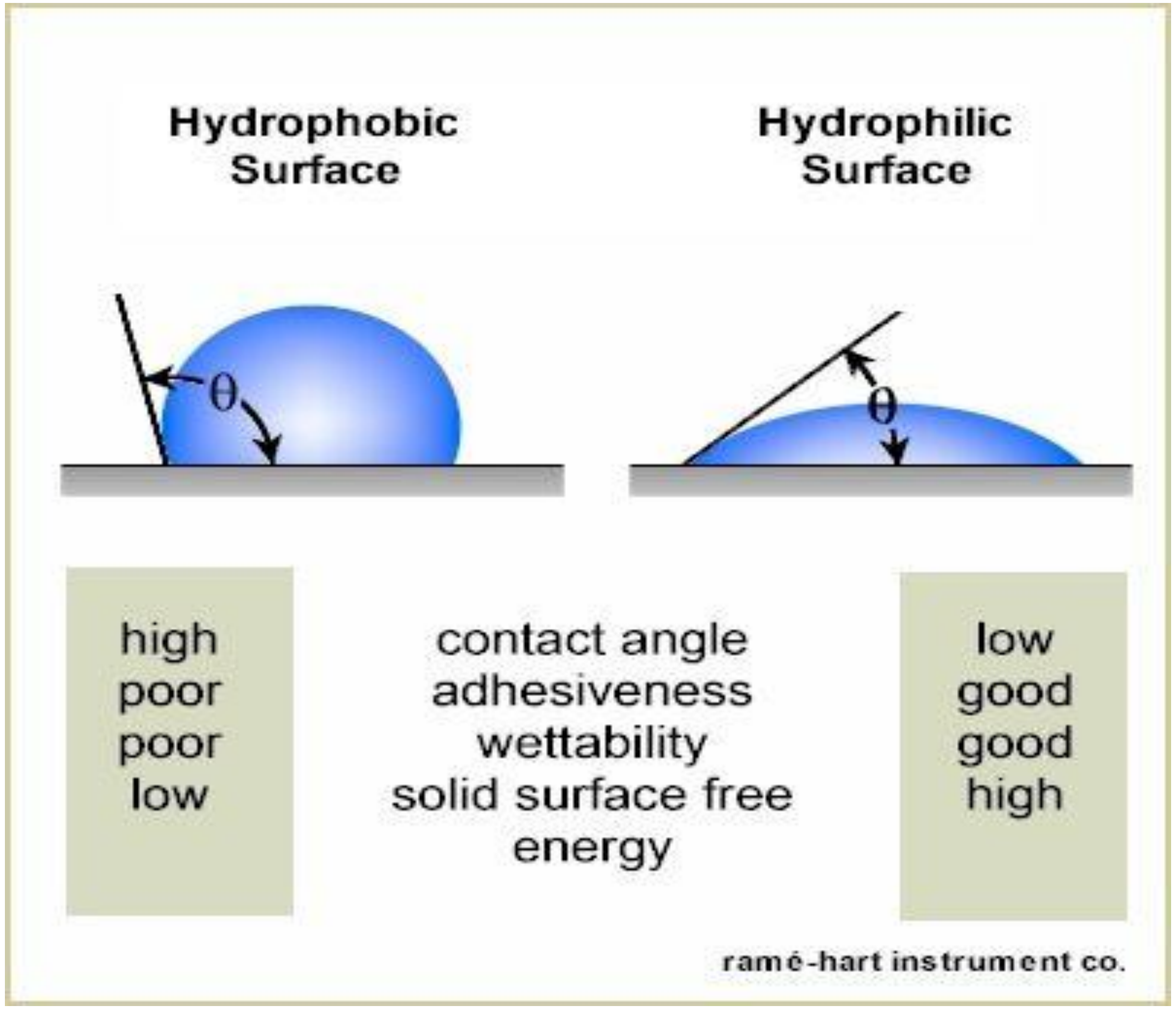
Contact Angle Overview

- Theoretical consideration
  - Dirty surface: high contact angle/low energy (adsorbed H_2O, hydrocarbon, etc.)
  - Clean Surface: low contact angle/high surface energy (more hydrophilic/ higher wettability, better adhesion)
- Experimental consideration
  - Before plasma – HIGH contact angle reading
  - After plasma – LOW contact angle measurement



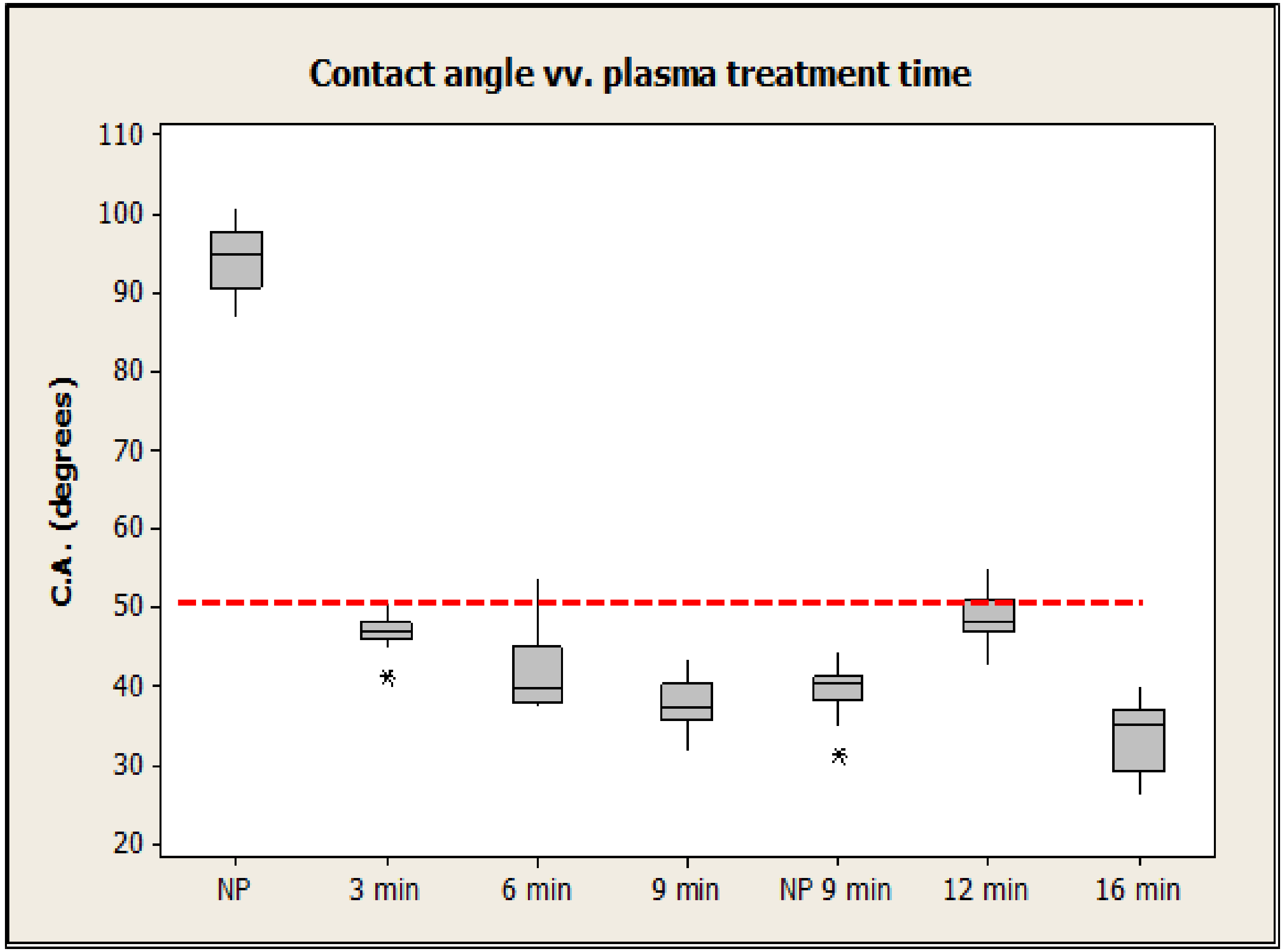
Contact Angle Response on Plasma Treatment

- Need to know how effective the plasma treatment is
- Establish a quick response parameter that can be used in the production
- General response of surface after plasma treatment
  - Surface becomes hydrophilic, higher surface energy
  - Hydrophilic surface means cleaner surface (but not always!)



Contact Angle Experiments – Batch Plasma

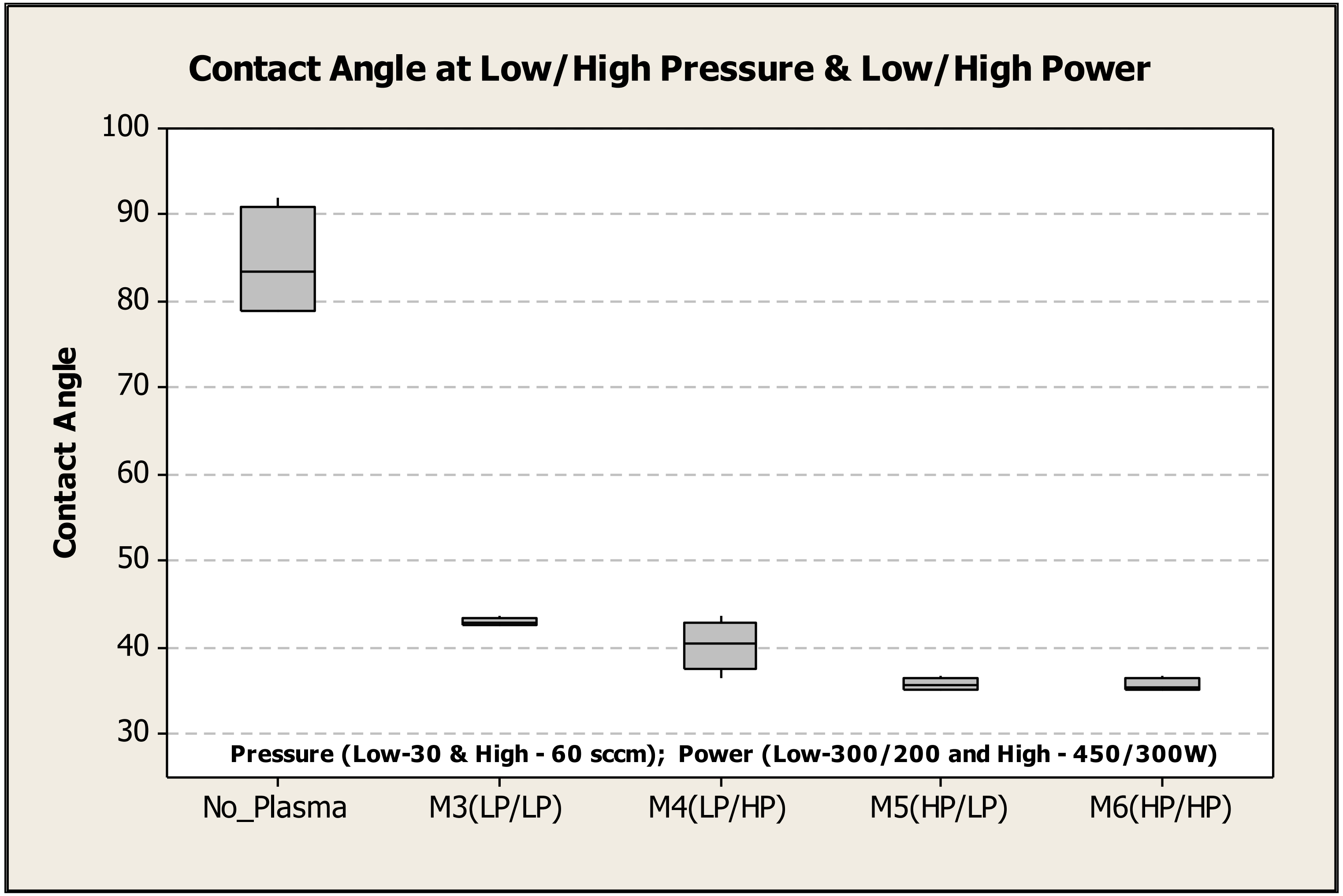
- Used batch plasma system
- Used PPF (pre-plated leadframe) sample strips
- Measurement of contact angle (C.A.) on the leadframe area
- Contact angle (C.A.) values high without plasma
- Lower contact angle values after 3 min of plasma time
  - Achieved cleaning of thin layer of organic/C-based contaminants and trapped water vapor



Actual values measured on 8 sites

Contact Angle Experiments – sts Plasma

- Used sts indirect plasma system
- Used PPF leadframes samples
- measurement of contact angle (C.A) on the leadframe area
- Combination of low/high pressure (30 and 60 sccm) or low/high power e(200-450W) experiments
- Total treatment time <2 mins



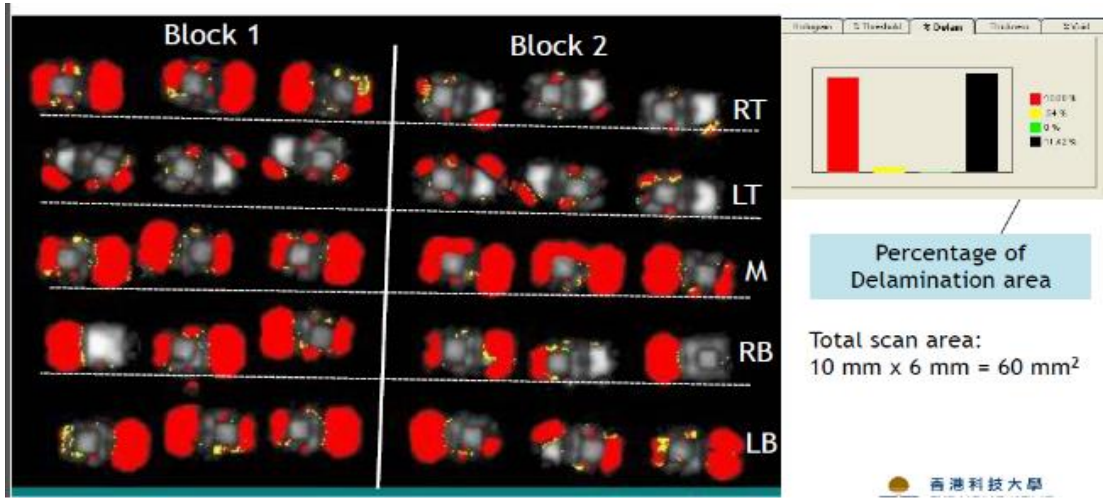
4.2 PLASMA RESPONSE: DELAMINATION

Delamination Improvement Using Plasma Cleaning

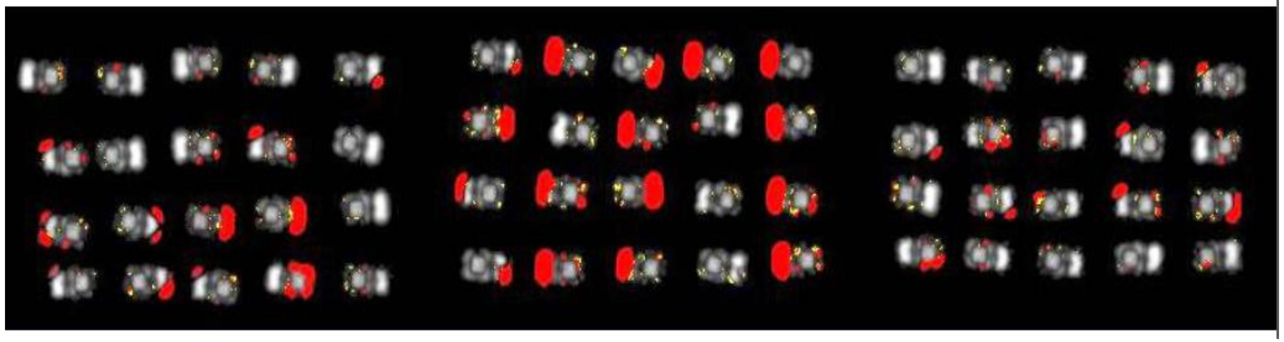
- Adhesion strength of mold/leadframe is due to both chemical and mechanical factors
- Thus, delamination is dependent on various factors including surface roughness, surface cleanliness, coating, oxidation, and post-mold curing process
- For PPF leadframes, improvement in surface cleanliness through plasma can contribute to delamination improvement
- For Cu leadframes, improvement in surface cleanliness and control of oxidation through plasma can contribute to delamination improvement
- *In this section, evaluation results are presented which were made on discrete and IC packages using batch and sts plasma, respectively*

Delamination – Batch Plasma Before Mold (Discrete Package – SOD882)

- Long treatment time using batch plasma (e.g. >10 min) can induce delamination
  - Recontamination on the surface during long treatment time (through resputtering and deposition)
- Use of delamination as a plasma response parameter in small discrete packages is not sensitive enough
  - other delam factors (package integrity, deflash methods, etc.)



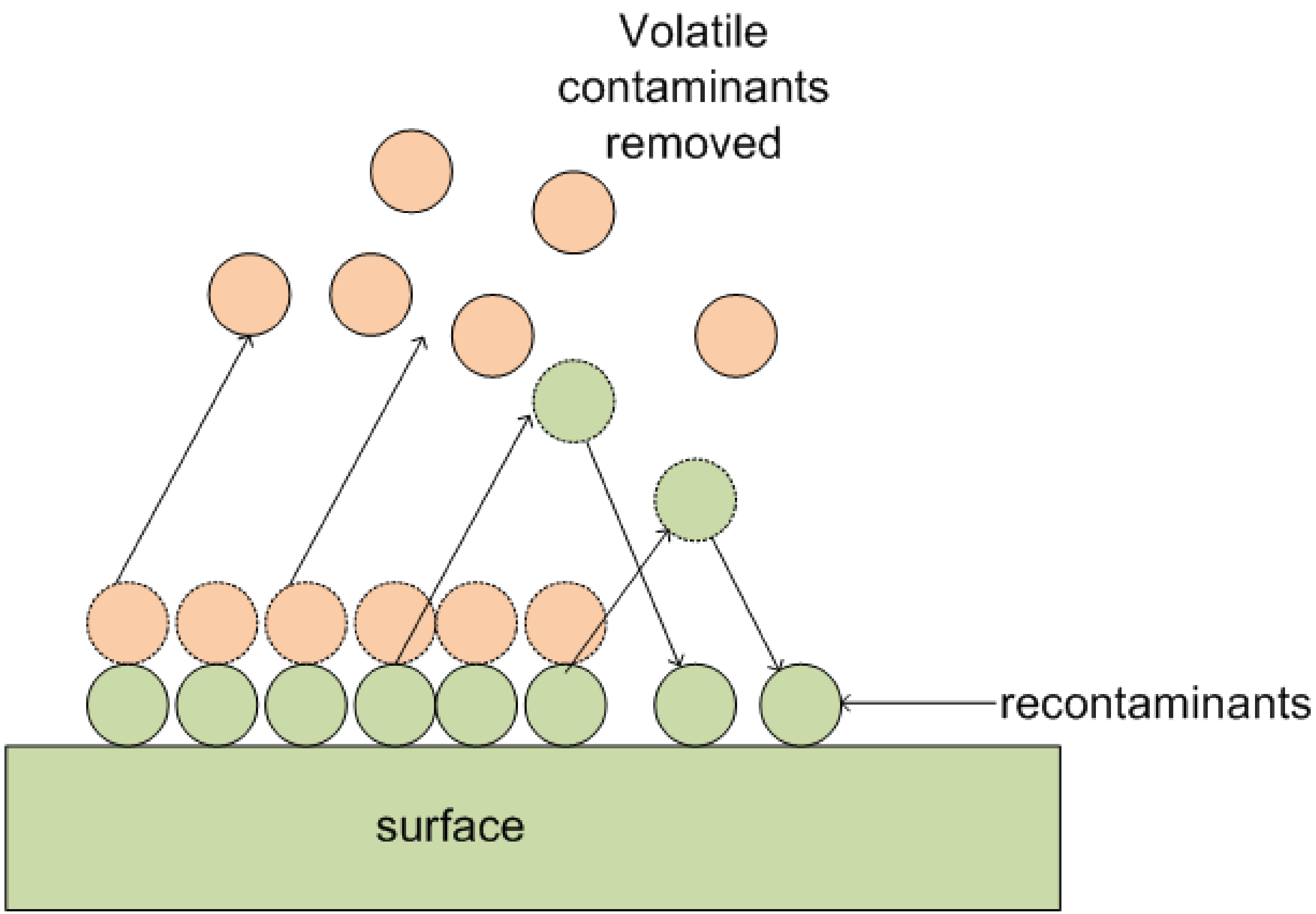
No Plasma	2X Plasma	sts Plasma
Sample 10.1	Sample 10.5	Sample 10.8



Why More Severe Delamination for Batch Plasma-treated PPF LF?

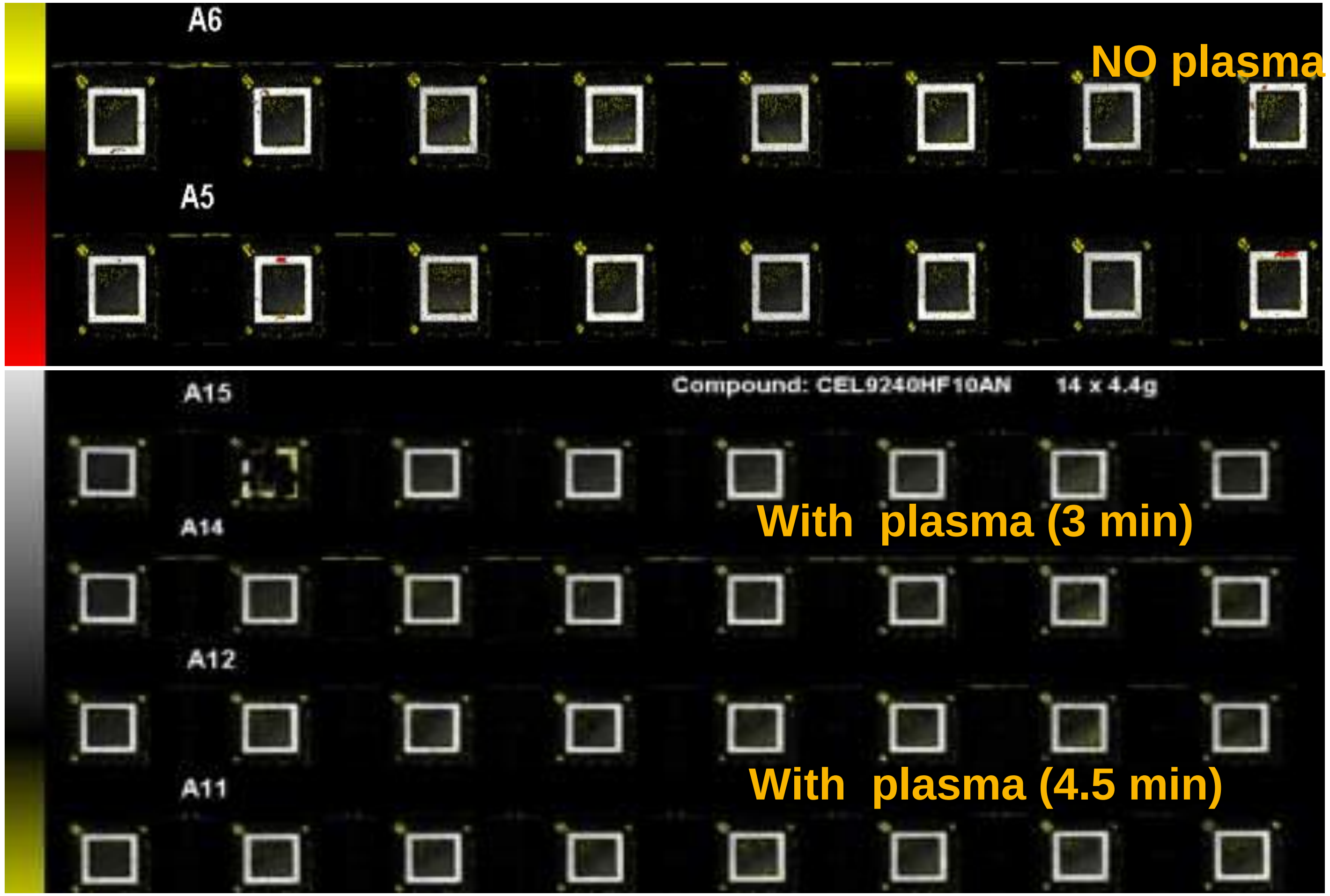
Hypothesis

- Sputtering of base material results to recontamination
  - Trace metals seen on LF surface using ToFSIMS
  - Redeposition of corrosive elements



Delamination – sts Direct Plasma Before Mold (IC Package – HLQFP100)

0-Hr SCAT (WB waiting time ~2.5 min)



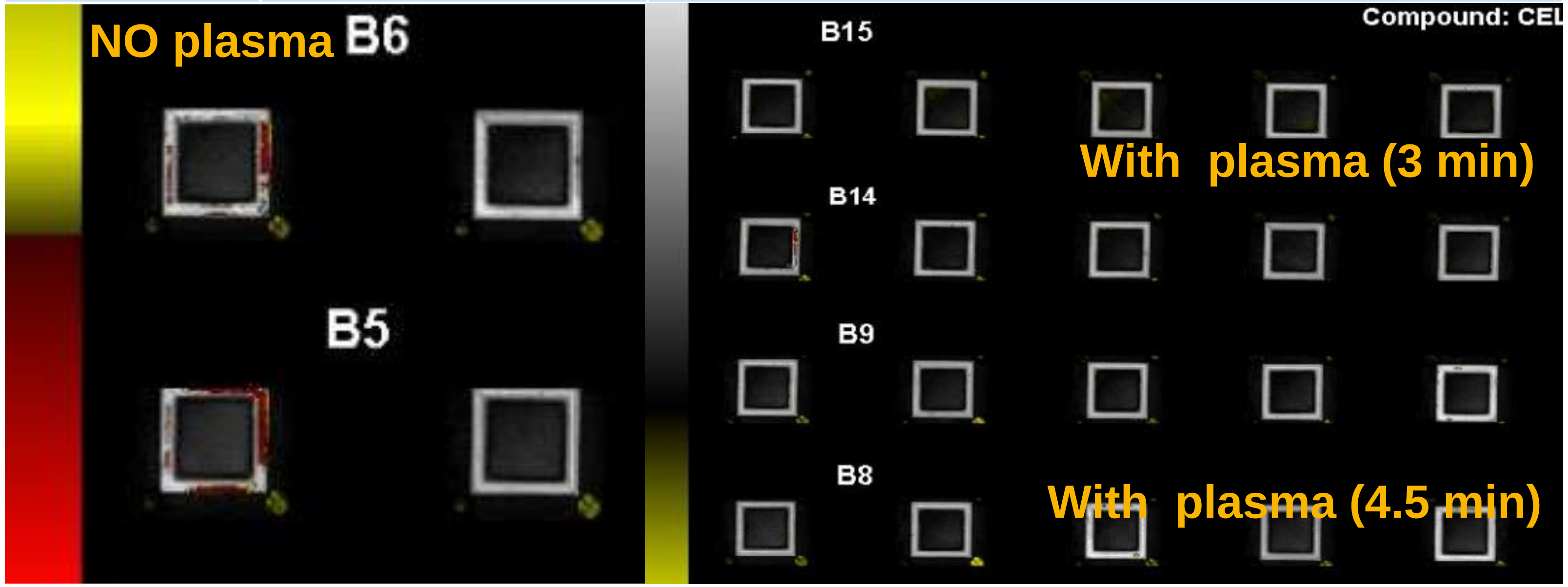
Sample	Strip Plasma	SCAT at 0h (die pad delamination)
A5-6	No plasma	4/8pcs, 1-10% delamination
A14-15	3mins	0/8pcs
A11-12	4.5mins	0/8pcs

- Delam seen untreated packages post-WB
- No delamination for plasma-treated packages
- No impact on delam at extended 1.5X plasma

Delamination – sts Direct Plasma Before Mold (IC Packages)

0-Hr SCAT (WB waiting time ~5 min)

Sample	Strip Plasma	SCAT at 0h (die pad delamination)
B5-6	No plasma	2/8pcs, 50-80% delamination
B14-15	3mins	3/8pcs, 1-10% delamination
B8-9	4.5mins	1/8pcs, 11-25% delamination



- Delamination seen on untreated leadframe
- Plasma treatment improved delamination response
- Waiting time at WB (~235^{o}C) also impact delamination i.e. >2.5 min
  - Additional growth of oxide

4.3 CASE STUDIES (CORROSION TESTS)

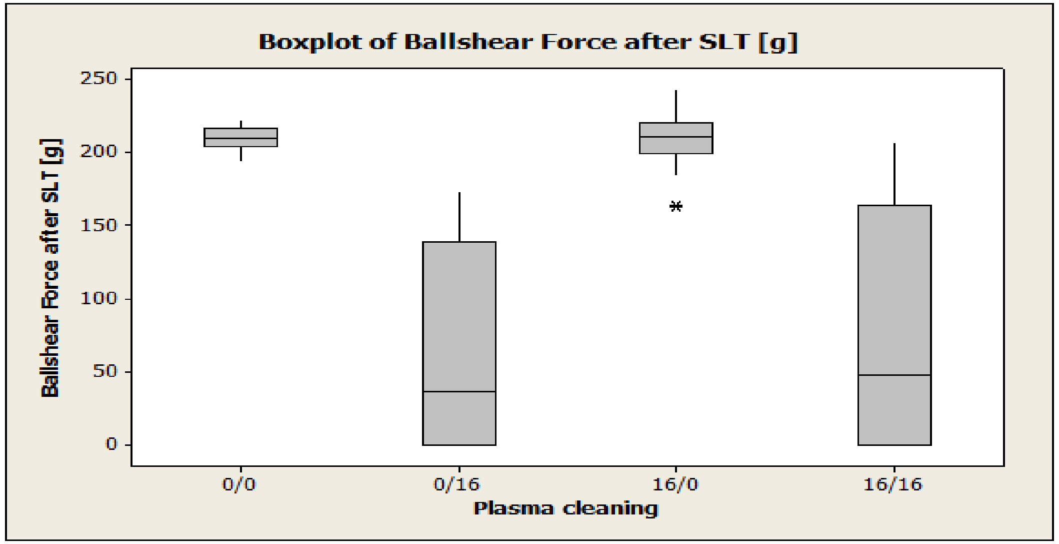
Corrosion Tests for Cu Wire

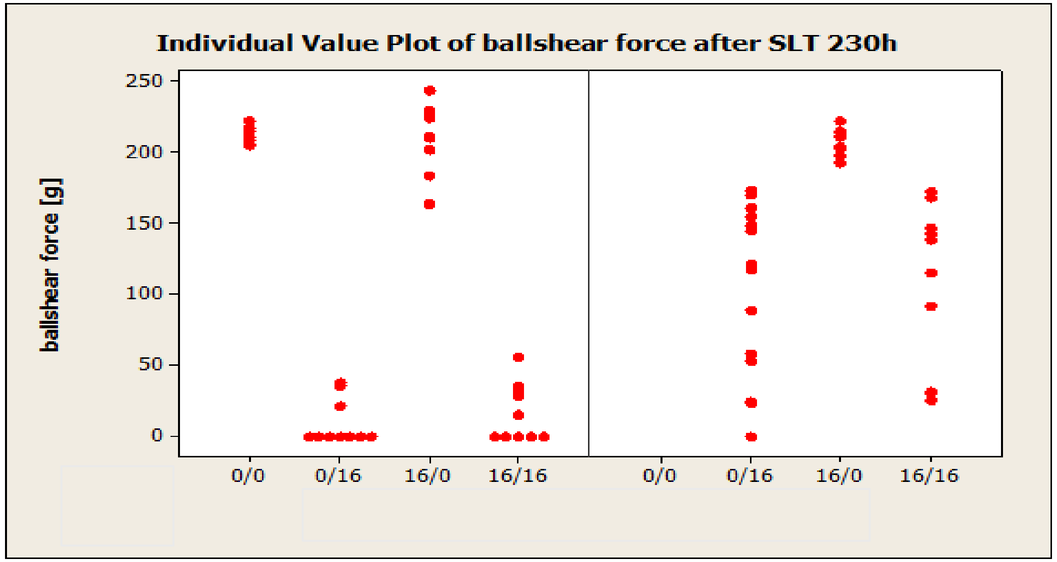
- Plasma evaluation was made to compare batch and sts plasma performance
- Evaluation was made on PPF leadframe using Cu wire on a small discrete package
- Batch plasma treatment run from 6-10 min (post die bond DB or post wire bond WB)
- sts 1X plasma treatment run for <2 mins
- Response is the corrosion test in which the package is subjected to corrosive environment, decapped and was tested for its bond integrity
- Surface analysis was also performed to check for surface cleanliness

Corrosion Test

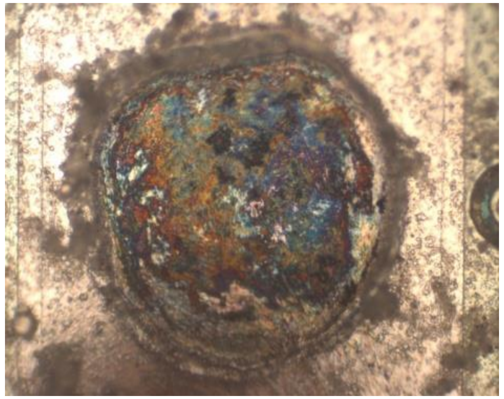
- Place flux on top of the devices
- Put in autoclave for 240 hours
- Perform electrical measurement (use curvetracer to see if emitter-base path along Cu wires is still good)
- Decapsulate 5 devices with acid suitable for Cu wire
- Perform ball shear test on 5 devices (10 bonds)

Case Study 1: Batch Plasma

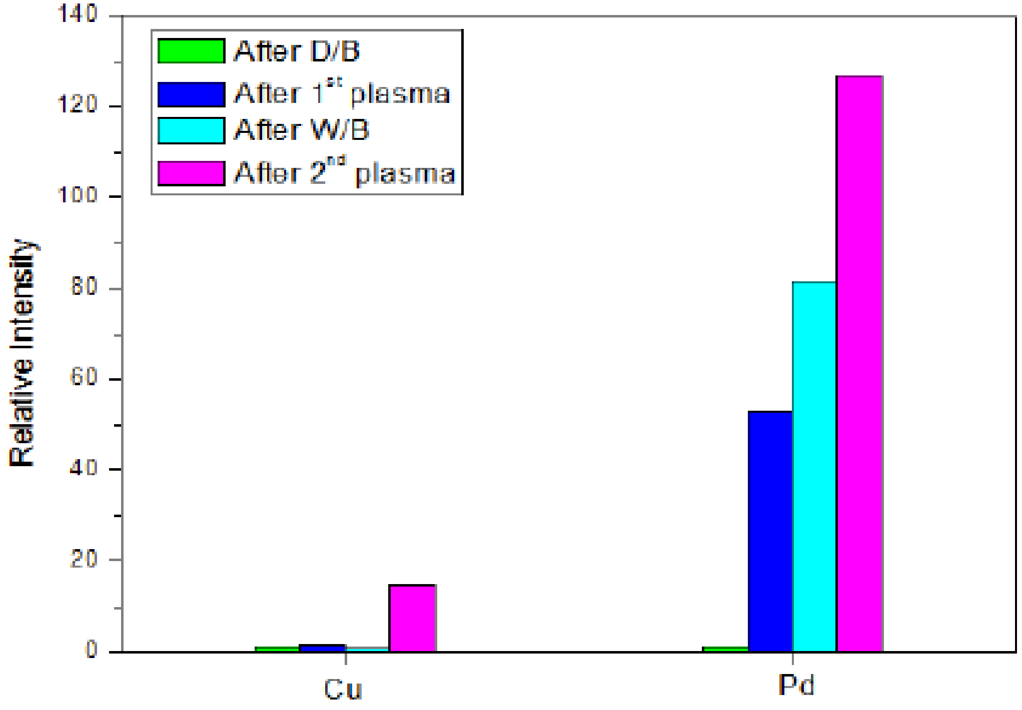


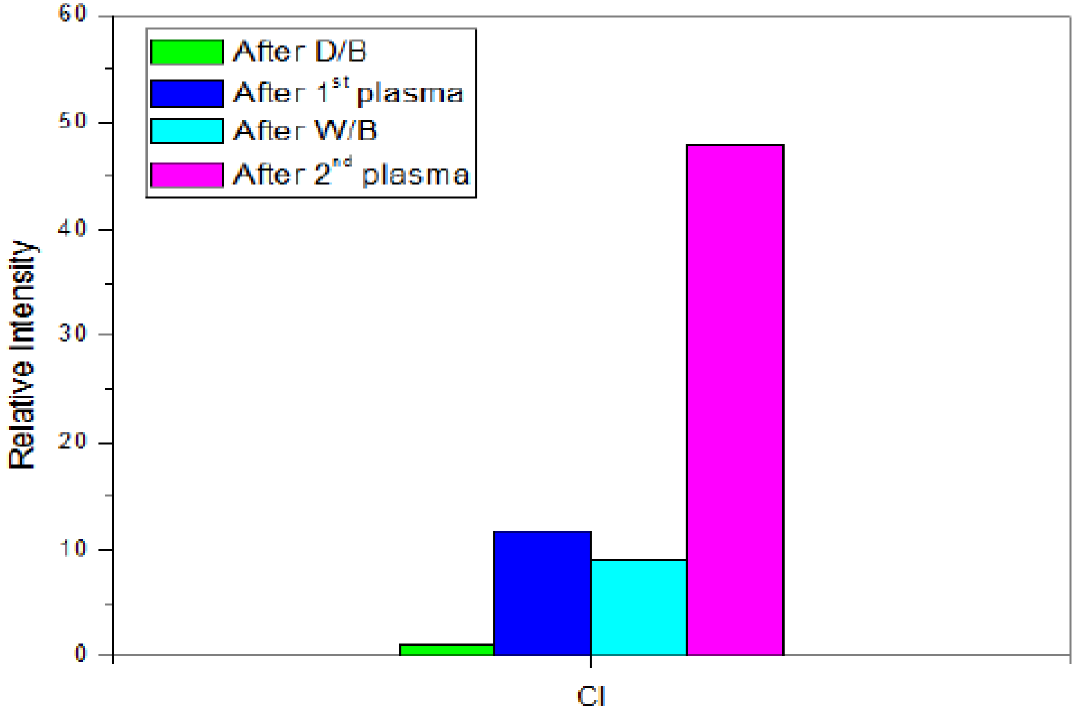


- Corrosion test is indicated as short loop test (SLT). Samples are subjected to flux containing Cl and storing samples under high pressure/temp/humidity environment @121oC, 100%RH.
- Plasma treated samples failed corrosion test, showed bond pad corrosion.
- Hypothesis: Plasma cleaning redeposits foreign material onto the bondpad which cause corrosion.



Evidence of Redeposition (Batch Plasma)

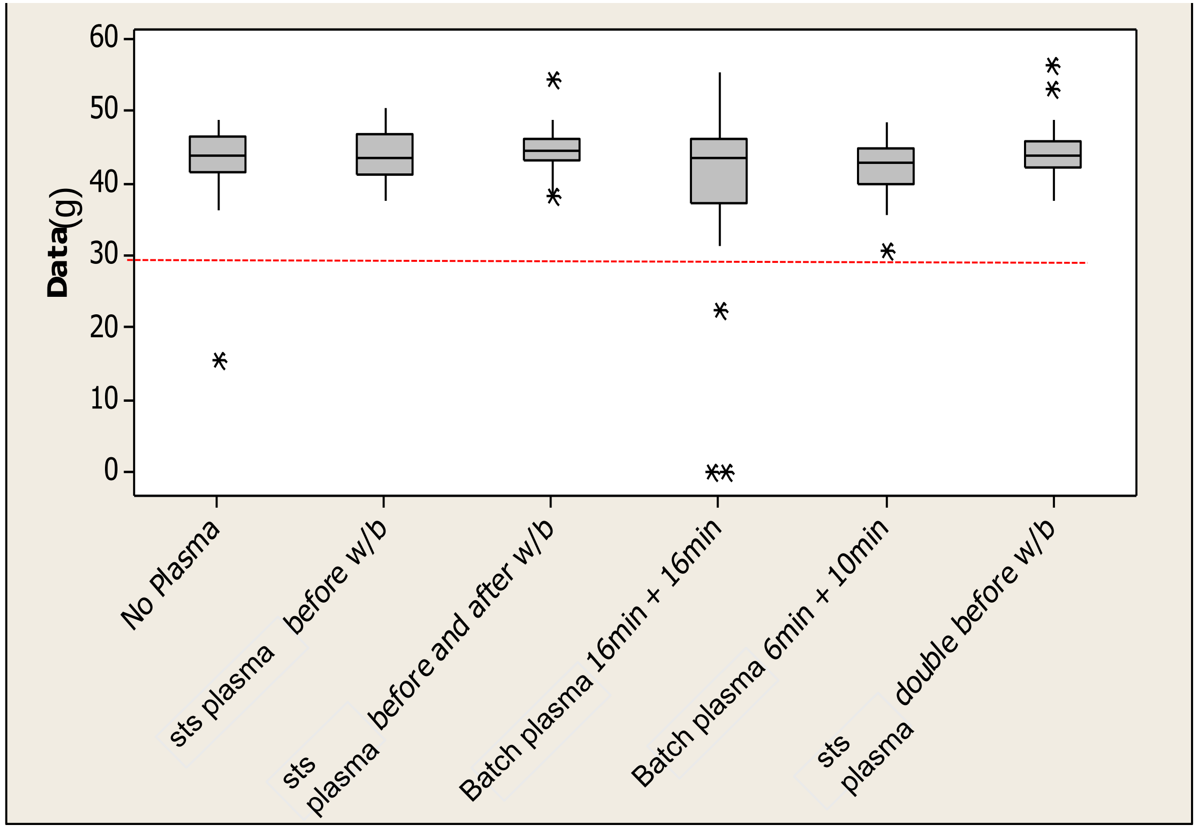




After plasma post WB (2nd plasma), Cu and Pd particles (from PPF leadframe) were redeposited on the bond pad surface

- After die bond (DB), Cl content is minimal
- Cl content increased after 1st plasma (post-DB)
- Further increase after 2nd plasma post wirebond (W/B)

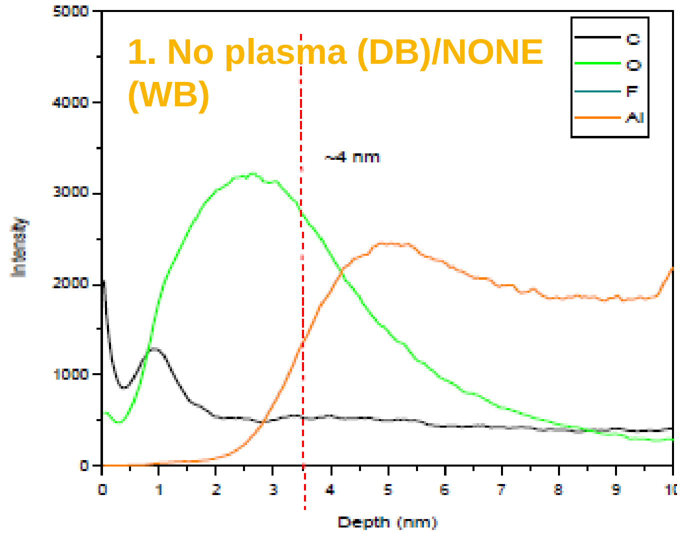
Case Study 2: sts vs Batch Plasma

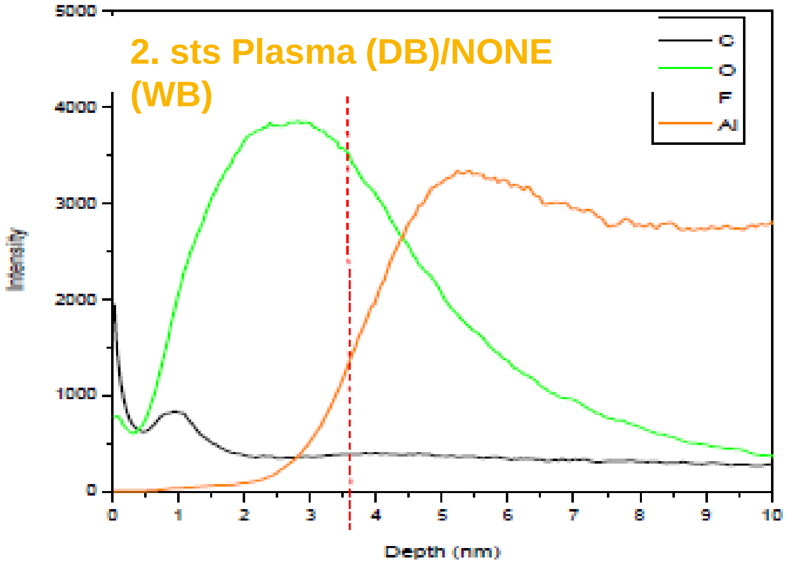


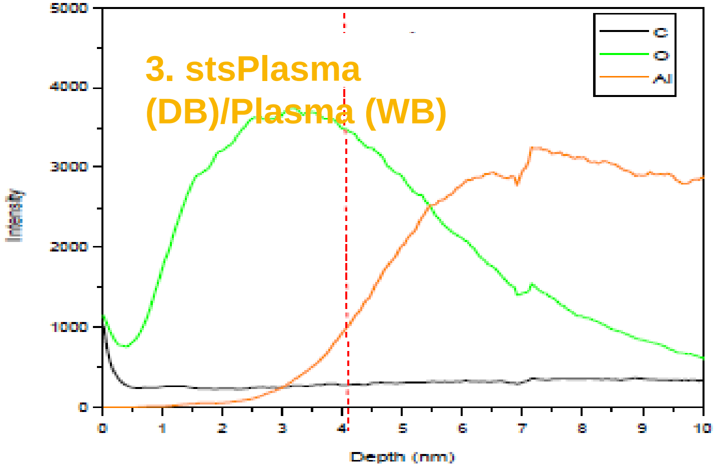
Short Loop Test (240h)

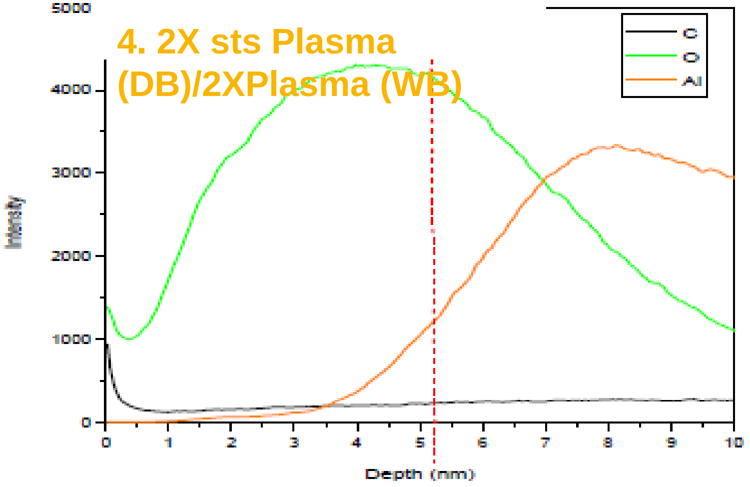
- sts plasma legs runs showed consistent high ball shear readings (i.e.>35g after Short Loop Test, indicating that the integrity of the ball bond is intact
- Batch plasma showed lower ball shear readings and indication of corrosion

Surface Analysis (sts Plasma)









1. No plasma (both post die bond DB and post wirebond WB) Thin hydrocarbon layer present
   - Plasma treatment on relatively clean bond pad
2. Plasma post WB, NO plasma post WB, reintroduced a thin layer of hydrocarbon
3. Plasma post DB and post WB showed total reduction of hydrocarbon with NO halogens induced
4. Extended treatment showed absence of hydrocarbon with NO halogen introduced into the bond pad (very clean surface!)

SUMMARY AND CONCLUSIONS

Summary and Conclusions

- In IC packaging, plasma cleaning is a straightforward process. It is used to clean surfaces to improve yield and reliability.
- But plasma cleaning is a complex process, thus some understanding of its mechanism and key parameters are presented.
- Plasma configuration play a significant role in deciding which system can give the optimum results.
- The conventional batch plasma systems is the default choice due to its robustness and compatibility for high volume. But at certain parameter and conditions, it is susceptible to recontamination.
- Different packages have different requirements and purpose. The user should be able to define these requirements and expectations.
- Industry trend in wire bonding technology indicate the shift from Au to cheaper but more process-sensitive alternatives such as Cu, coated Cu or Ag wire. Thus, compatible plasma cleaning technologies should be used for these requirements.

NEXT STEPS AND RECOMMENDATIONS

Next Steps and Recommendations

- For conventional packages (e.g. Au wire) that require cleaning of substrates and bond pads and are not sensitive to delamination, batch plasma can be used
- For packages which require specific improvement in delamination, sts direct plasma can be used. However, dwell time at higher temperature (e.g. at wirebonding) should be controlled
- For discrete packages using Cu wire and sensitive to recontamination, indirect sts plasma was found to be most appropriate
- Thus, for future plasma system requirements, next step is to phase-in sts indirect plasma in the production of all Cu wire packages

SECURE CONNECTIONS
FOR A SMARTER WORLD

ATTRIBUTION STATEMENT