SEMICONDUCTOR PROCESSING
With ONTOS ATMOSPHERIC PLASMA

Eric Schulte, February 2017
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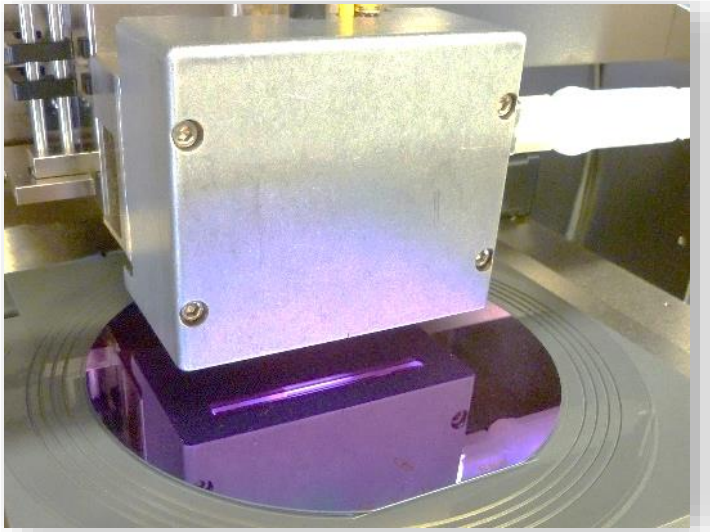
CONTENT

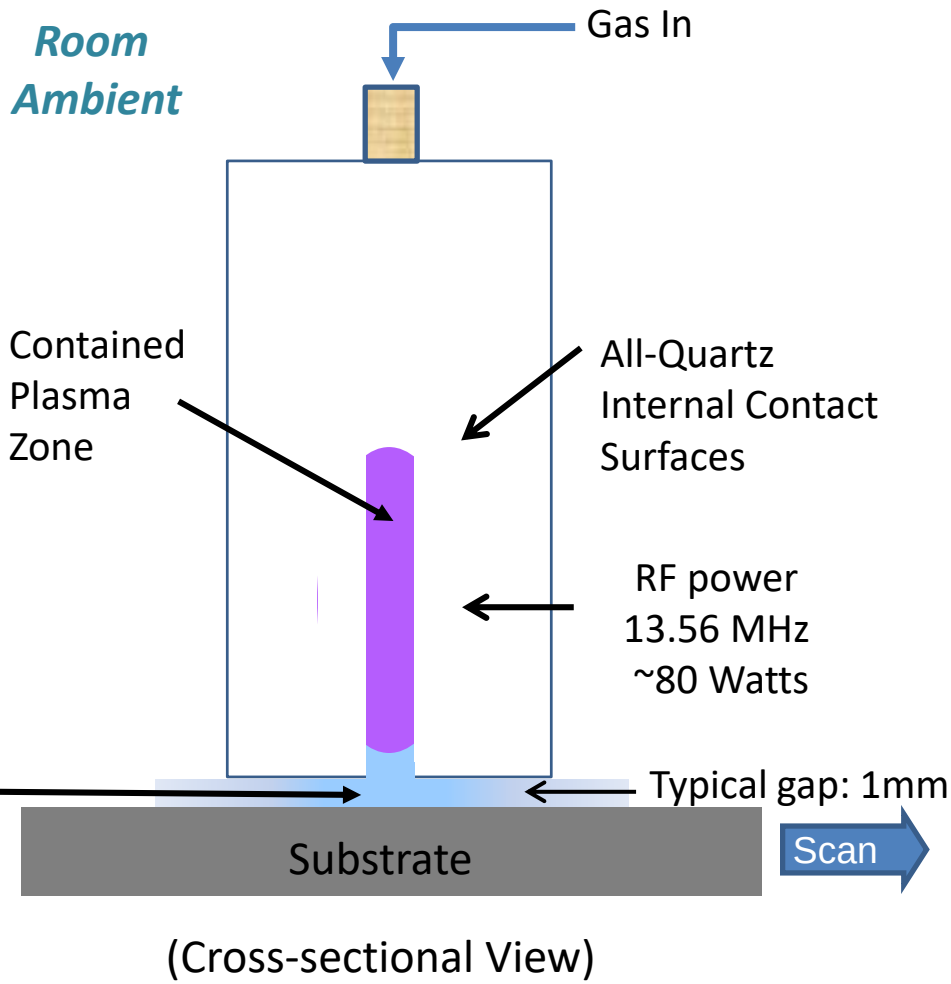
SETNA

- **General Overview**
- Physical Chemistry Insights
- 11 Specific Applications in Semiconductor Manufacturing
- Production Systems for High-Volume Manufacturing
- Conclusions
- About SETNA
- Backup – Competitive Advantages of Ontos

Ontos7

WHAT IS ONTOS ATMOSPHERIC PLASMA ?



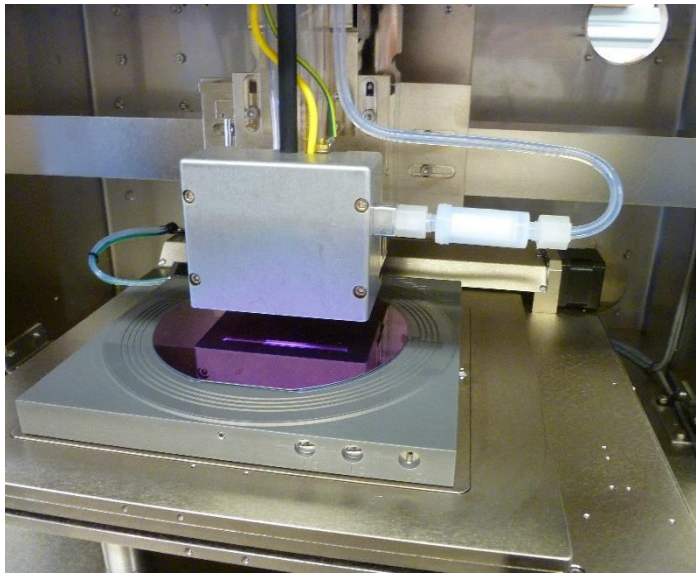


Downstream active radicals

- Cool gas (<100°C).
- No ions, no hot electrons.
- Outward flow excludes atmosphere from process zone.

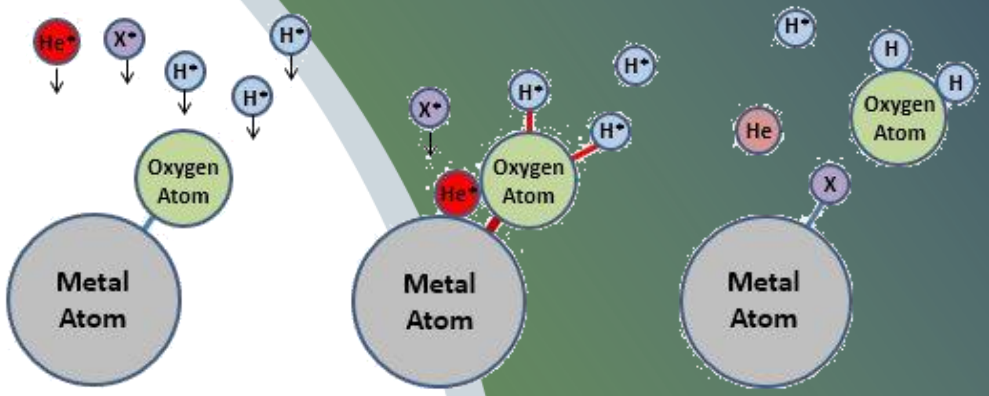
OTHER ONTOS ATTRIBUTES

Simple, Effective and **Safe** Process



- **Simple** process - no vacuum chamber.
- **Fast -** completes in a few minutes
- **Downstream** radical chemistry only
- **Safe** for devices and personnel
  - **No** arc discharges, ions, bombardment, re-deposition, or spalling particulates.
  - **CMOS safe, compound semiconductor safe.**
  - **Non-toxic, dry** process. OSHA- and EPA-friendly.
  - **CE-Mark** (third party inspection)
- Easy installation
  - 120-240V/50-60Hz power, process gasses, & house exhaust.

SETNA



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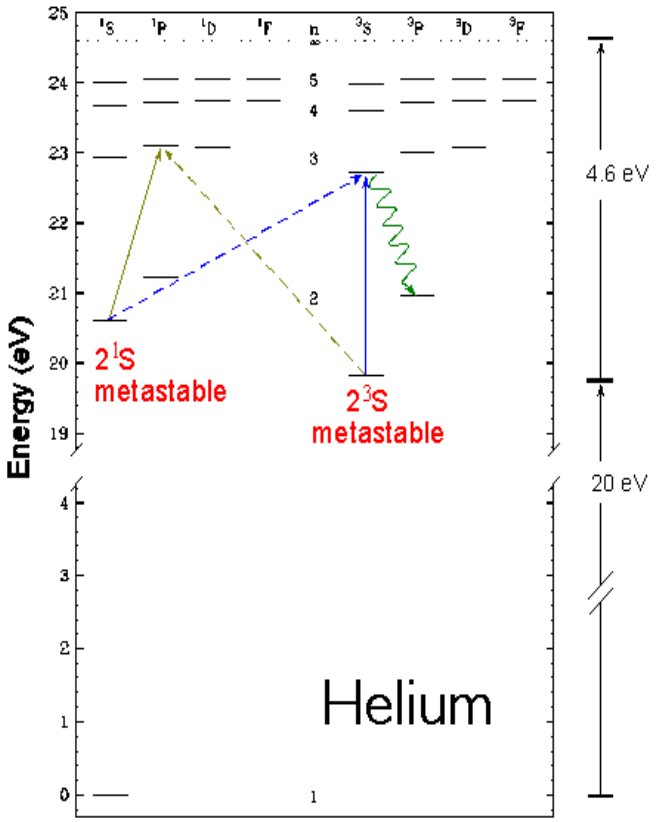
QUANTUM ENERGETICS ACTIVATE SURFACE REACTIONS

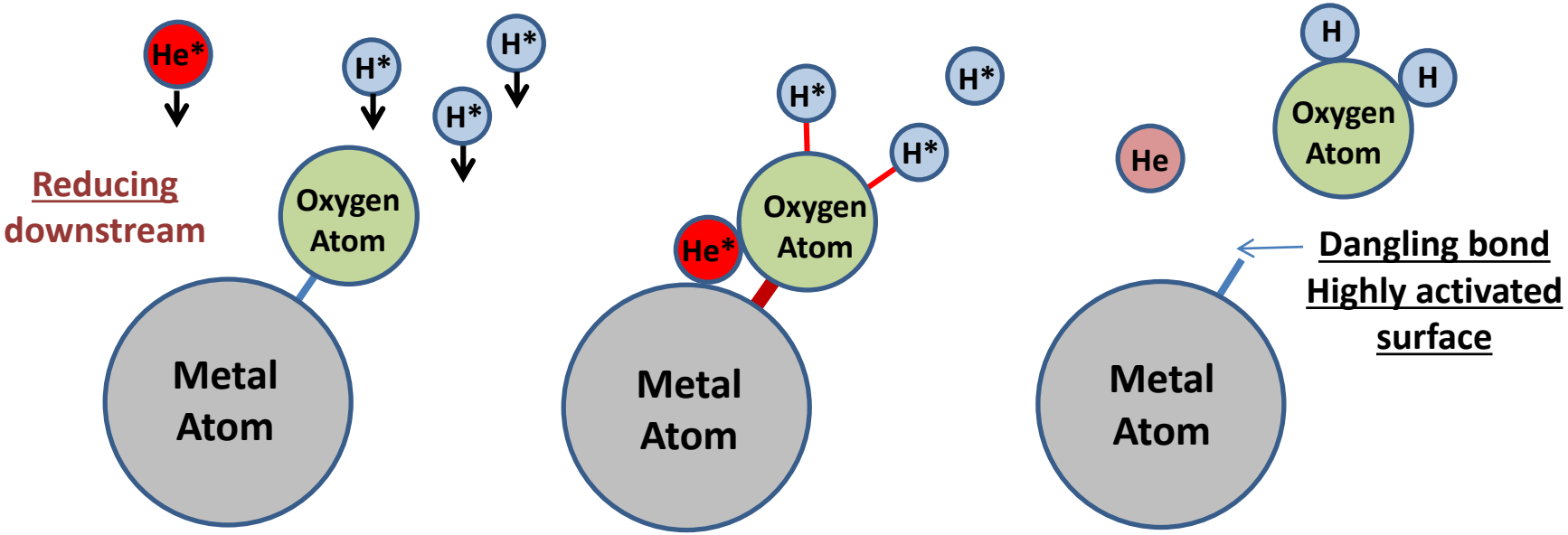
- Helium (our carrier gas) has two metastable energy levels (2^1S and 2^3S) at 19.8 and 20.6 eV.
- Once an electron is excited into this state (by RF plasma), it can only decay back to ground state by physical collision with other atoms.
- This occasionally occurs in the gas phase, but occurs strongly as the metastable Helium atoms contact the substrate surface.
- This contact transfers quantum energy directly to the surface atoms and provides extra activation energy for surface chemical reactions.



[Note: Energy transfer from He 2^1S and 2^3S are the principal source of excitation for the HeNe laser]

QUANTUM ENERGETICS ACTIVATE SURFACE REACTIONS

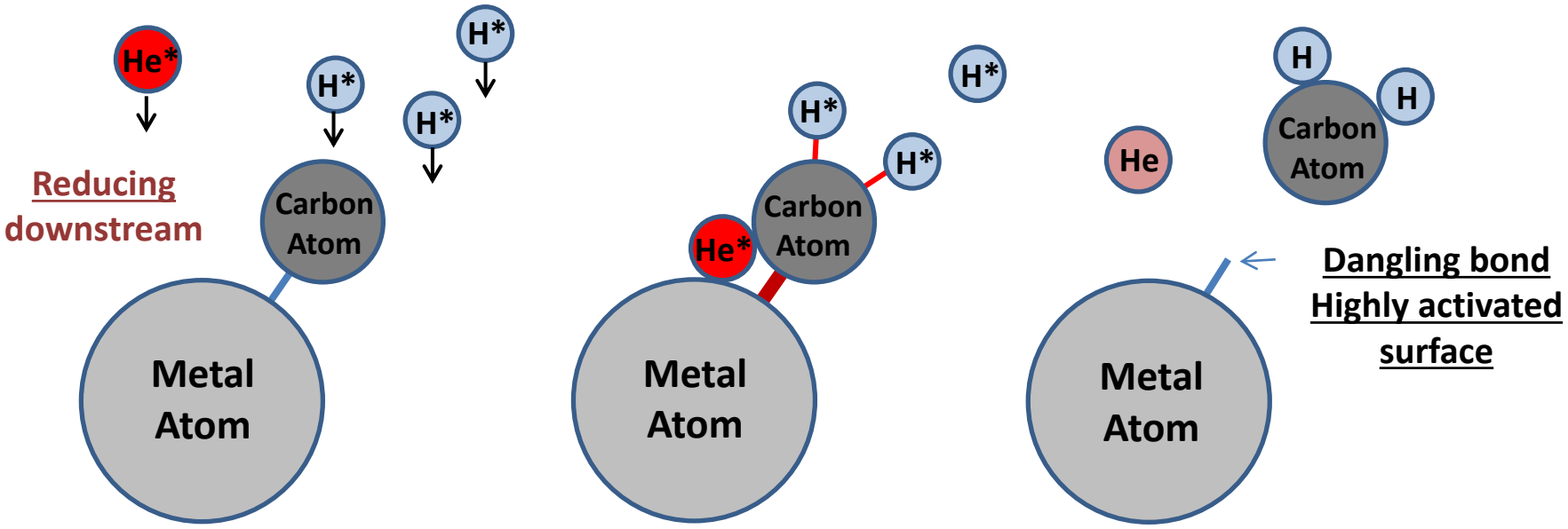
- This is somewhat analogous to the surface activation that occurs in R.I.E., except there is essentially ZERO kinetic energy transfer occurring, and therefore, zero kinetic (bombardment) damage to the substrate.
- This is highly desirable for preparing the surfaces of sensitive semiconductor structures.



Oxide can be reduced from In, Sn, Ni, Cu, Sb, Ag, Au, and more.

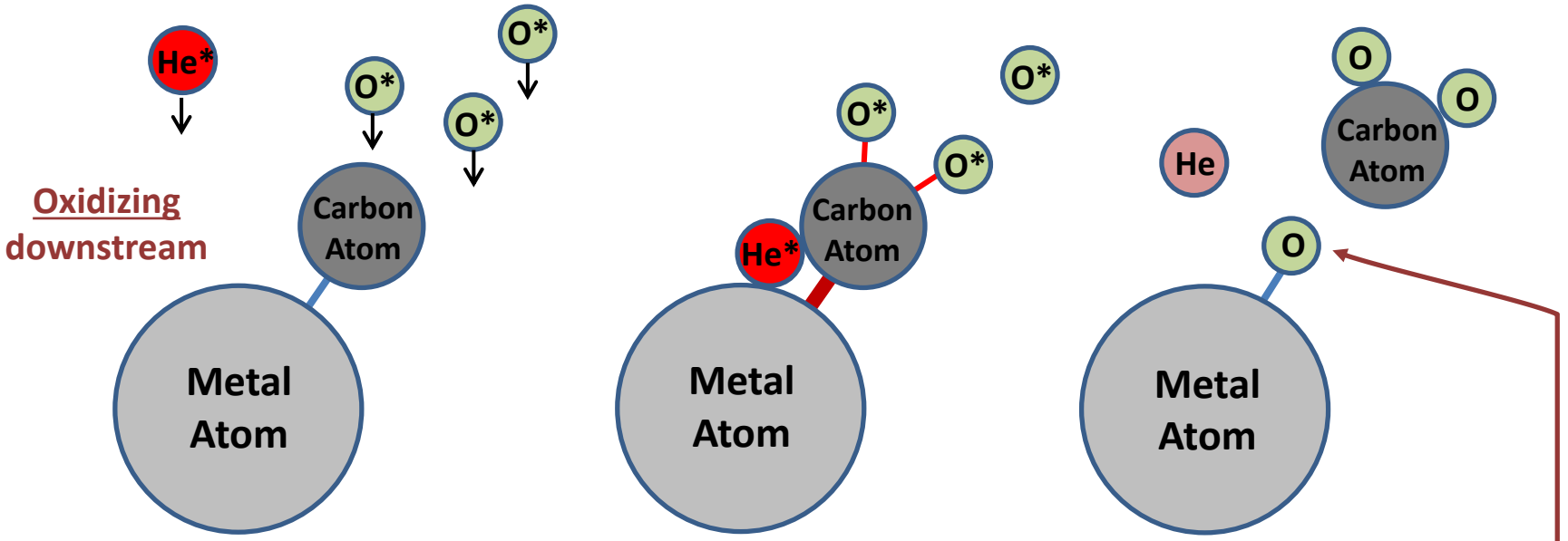
QUANTUM ENERGETICS ACTIVATE SURFACE REACTIONS

Similar reactions on Carbon (organics) with Reducing Chemistry



QUANTUM ENERGETICS ACTIVATE SURFACE REACTIONS

Similar Reactions On Carbon (Organics) with Oxidizing Chemistry

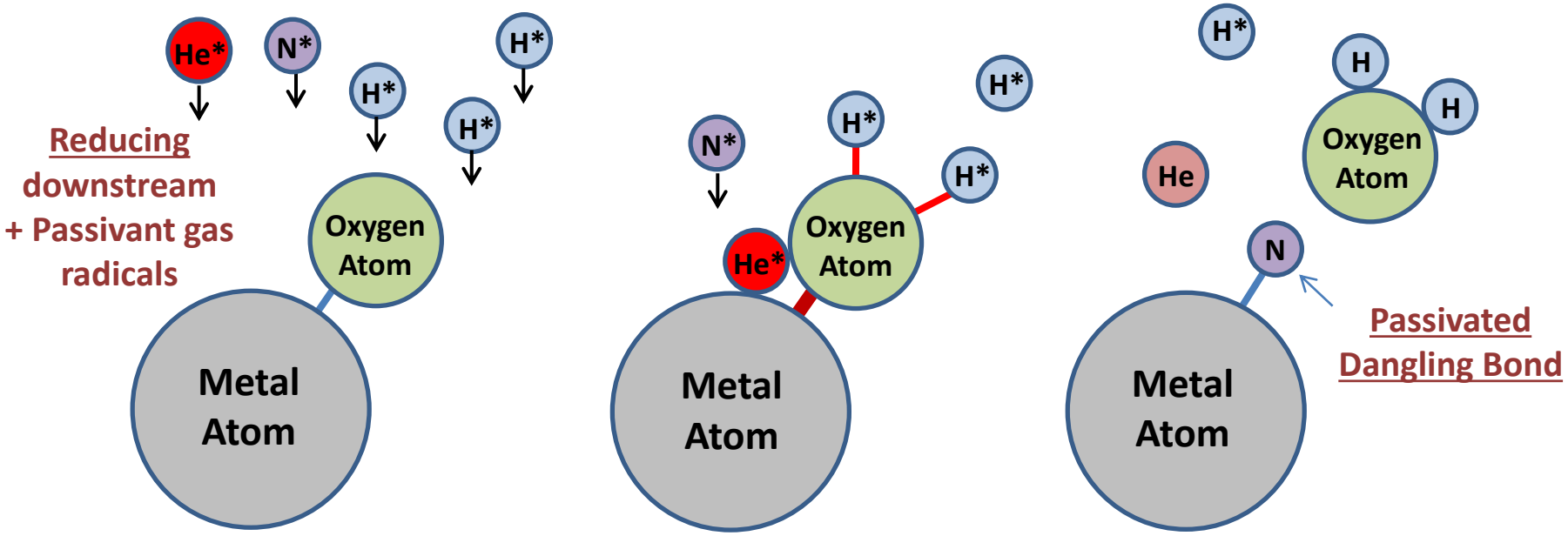


The metal atom dangling bond is now terminated with Oxygen!

Possibly a method to control oxidation stoichiometry: *Passivation!*

QUANTUM ENERGETICS ACTIVATE SURFACE REACTIONS

Other gasses can be used to passivate dangling bonds against re-oxidation

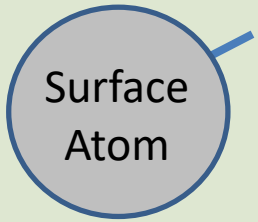
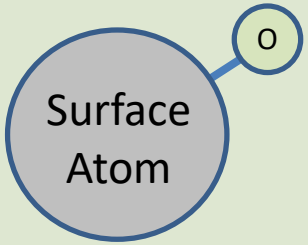
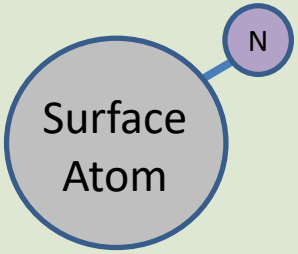


Typical passivation lasts for many hours on metals; can last for days on dielectrics, photoresist.

SURFACE ACTIVATION

Activated surfaces are more receptive to subsequent surface processes

- Different types of Activated Surfaces can be achieved with Ontos:

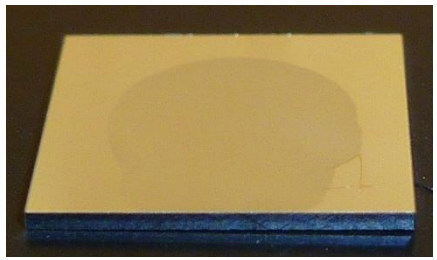
Dangling Bonds	Oxygen-Terminated	Nitrogen-Terminated
		
• Unstable surface. • Suitable only if created and maintained in an inert environment or high vacuum chamber	• Photoresist adhesion • Dielectric adhesion • Wet etch dielectrics • Passivation • AR coating adhesion • Direct SiO, SiO_2 Bonding	• Epi Growth • Adhesive Assembly • Passivation • Direct S/C Bonding • Direct Si_3N_4 Bonding • Wire Bonding • Bump Bonding • Wet etch metals

SURFACE ACTIVATION WITH ONTOS7

- **Surface energy is a critical parameter for all types of aqueous and adhesive processing.**
  - Wet etching.
  - Plating.
  - Rinse/clean.
  - Soldering.
  - Adhesives.
- **Surface energy measurement (water droplet contact angle):**

Example: SnAg

Before Ontos ⟷ **After Ontos**



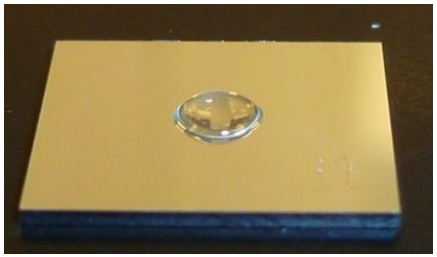
High contact angle –
- Lower surface energy
- Poor wetting
- Poor cleaning efficiency
- Low adhesion

Low contact angle –
- High surface energy
- Best wetting
- Best cleaning efficiency
- Best adhesion

- **Ontos has provided successful surface activation of: II-VI's, III-V's, Si, SiO2, Si3N4, photoresist, FRB, resins, polymers, Cu, In, Ni, Au, Ag, Al, Sn, SnAg, Ti …**

SURFACE ACTIVATION WITH ONTOS7 (EXAMPLES 1/3)

SnAg



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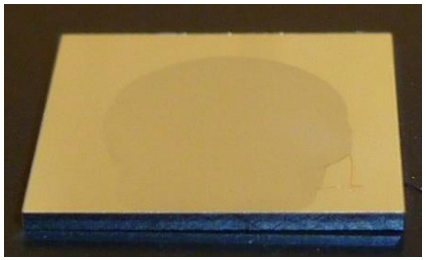
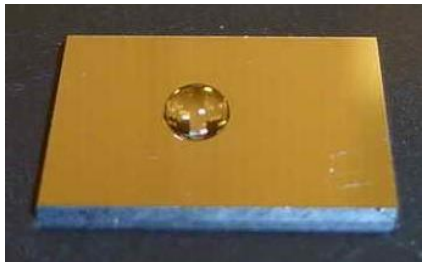


After Ontos7

Nickel



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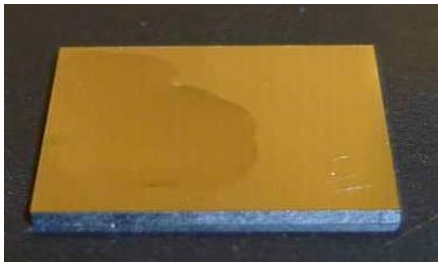
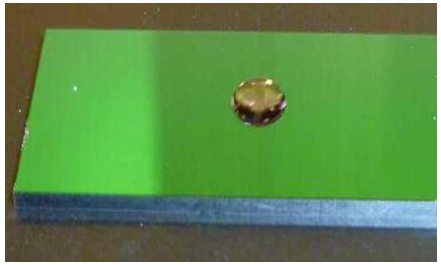


After Ontos7

SiO2



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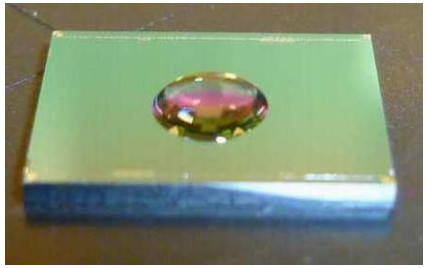
After Ontos7

Si3N4



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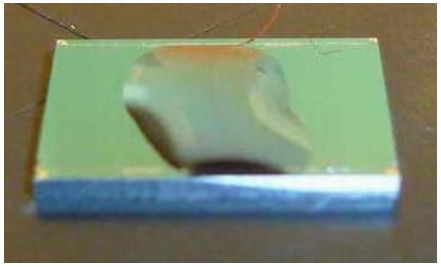
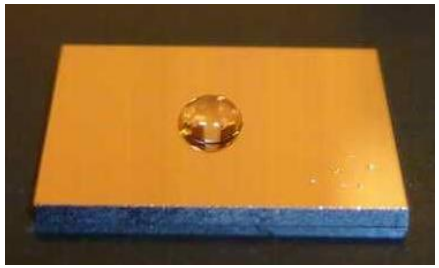


After Ontos7

SURFACE ACTIVATION WITH ONTOS7 (EXAMPLES 2/3)

Copper



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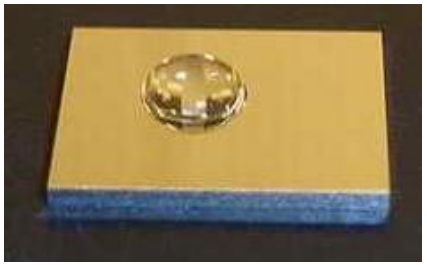
After Ontos7

Aluminum



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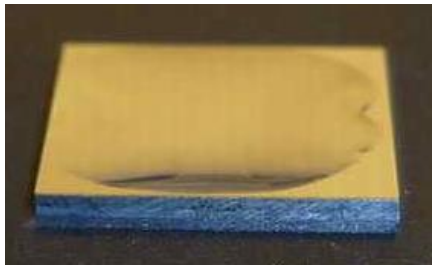

After Ontos7

Photoresist

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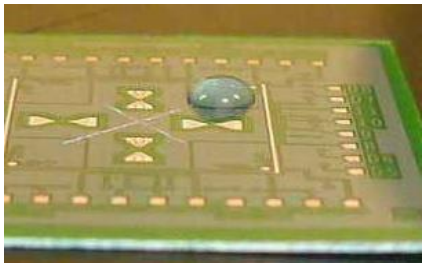
After Ontos7

Composite



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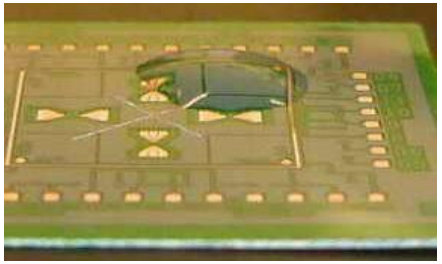
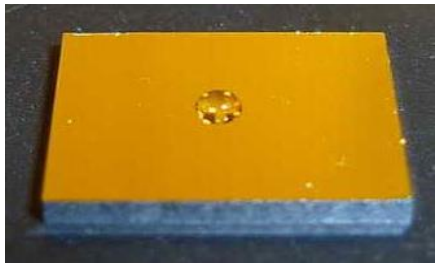


After Ontos7

SURFACE ACTIVATION WITH ONTOS7 (EXAMPLES 3/3)

Gold



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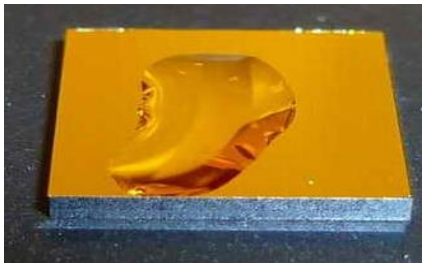

After Ontos7

Tin

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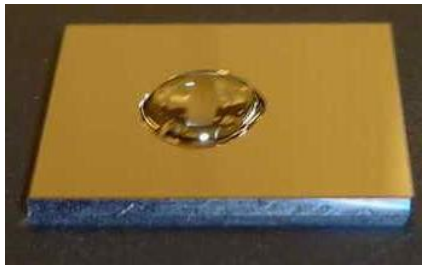
After Ontos7

Indium

untreated

After Ontos7

Titanium



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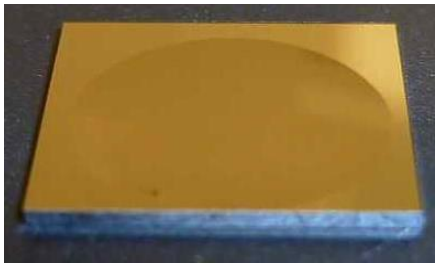

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Ontos7

1. STARTING WAFER CLEANUP

- What's on YOUR starting wafer?
  - Thin organic residue from polishing,
  - Chemical residue from etching,
  - Uncontrolled surface sub-oxides,
  - Adsorbed water and hydroxyls,
  - Organic contamination from packaging, handling, incoming inspection.
- Be sure you are starting with a "clean slate"
  - Ontos removal of atomic-scale contaminants from the wafer surface.
  - Passivation of the surface against re-gettering of Oxygen, Carbon, H2O, etc.
  - Surface activation of the wafer for subsequent processes.
  - Ideal for epi growth, implant, diffusion, passivation, …

2. PHOTORESIST DESCUM AND ACTIVATION

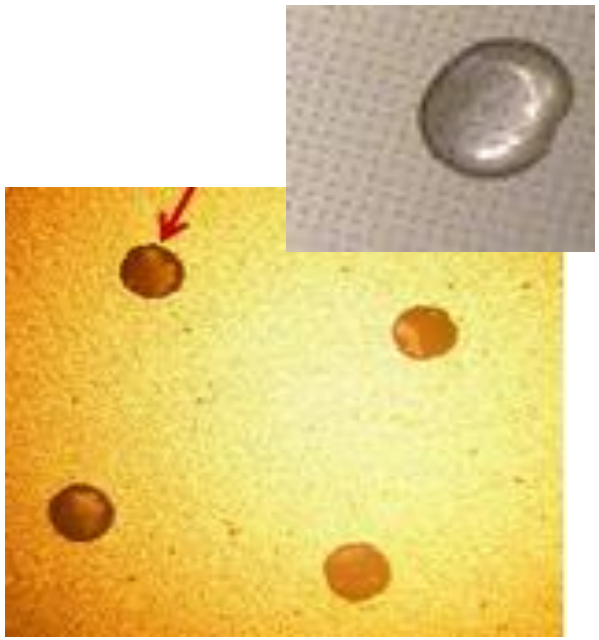
Improve the yield of Photoresist-patterned processes

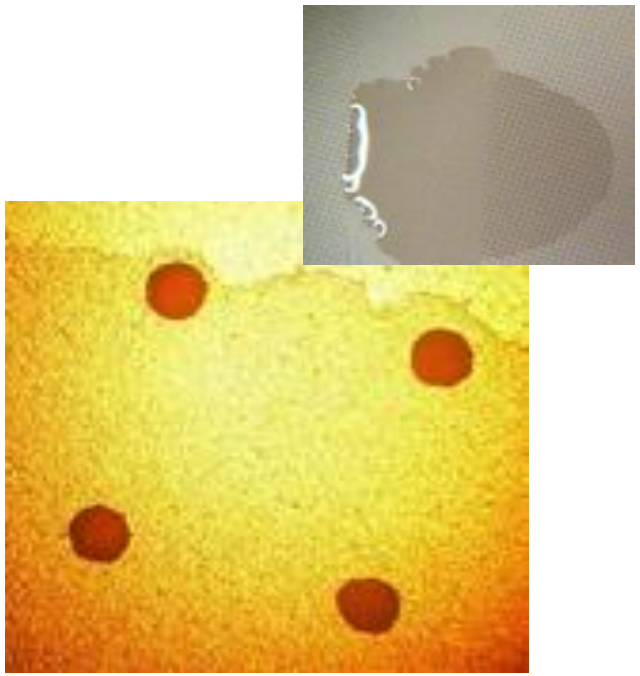
- Ontos removal of photoresist residue from previous mask steps **Replace Oxygen Ash, UV Ozone**.

- Descum of new PR pattern: Get excellent wetting **Replace Oxygen Ash** (which does not activate and alters linewidth).

- Surface activation of the photoresist for subsequent processes:

2. Activation of photoresist for Wetting





***Without* Atmospheric Plasma**

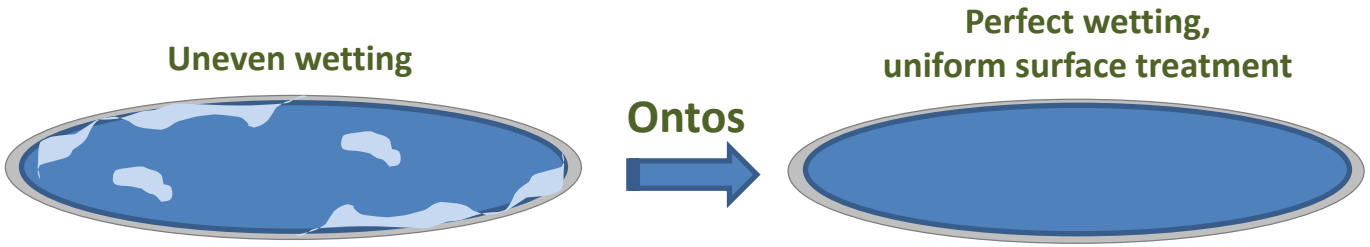
- Entrapped air prevents aqueous solution from entering small PR features.

***With* Atmospheric Plasma**

- Surface-activated photoresist draws plating solution into smallest PR features.

Improve uniformity, eliminate organic-induced non-wetting:

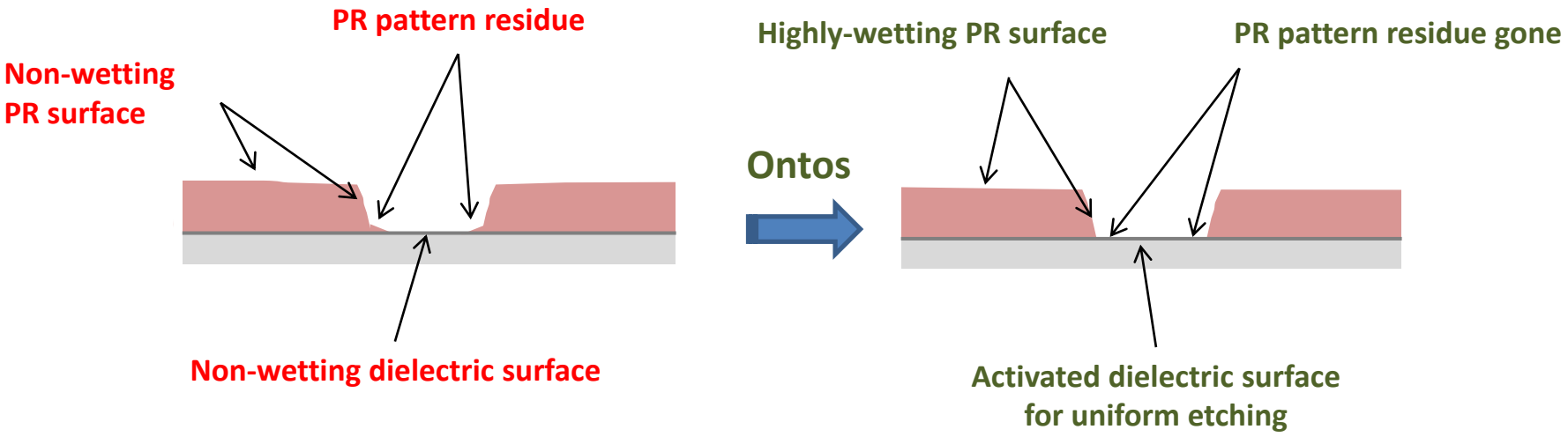
- Ontos removal of sub-oxide residue from wafer storage in atmosphere.
- Ontos removal of organic residue from wafer storage, handling.
- Surface activation of the wafer for perfectly uniform wetting



4. DIELECTRIC WET ETCH

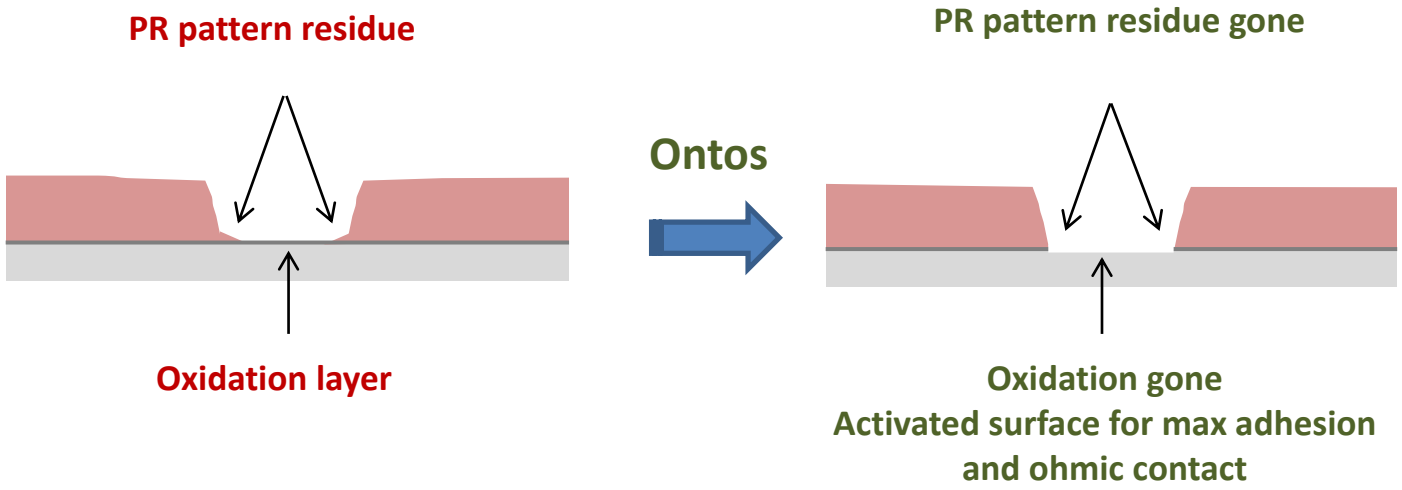
Use Ontos with **Oxidizing** Chemistry prior to wet etch

- Descum the PR pattern to remove bottom residue.
- Activate the surface of photoresist and dielectric for best wetting
  - Improves etching uniformity; no bubbles, no skips.
  - Reduces need to "over-etch" to clear small geometries.



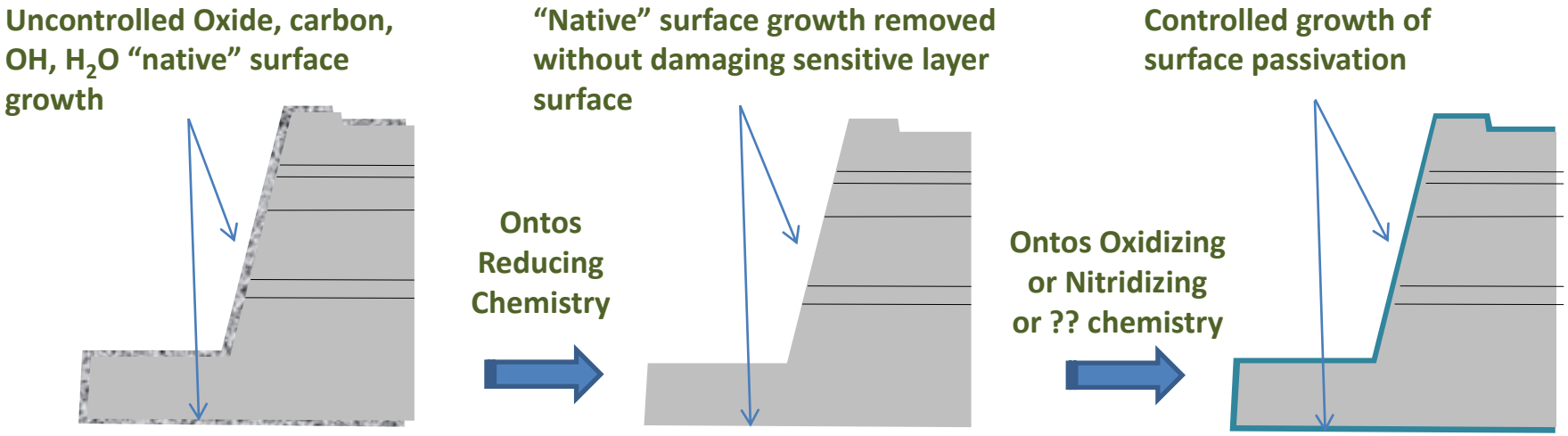
Use Ontos with **Reducing** Chemistry Prior to Metal Deposition

- Descum the PR pattern to remove bottom residue (without Oxygen!).
- De-oxidize the exposed surface for better ohmic contact.
- Activate the contact surface to improve adhesion of new metal layer.



6. PASSIVATION OF DELICATE SURFACES

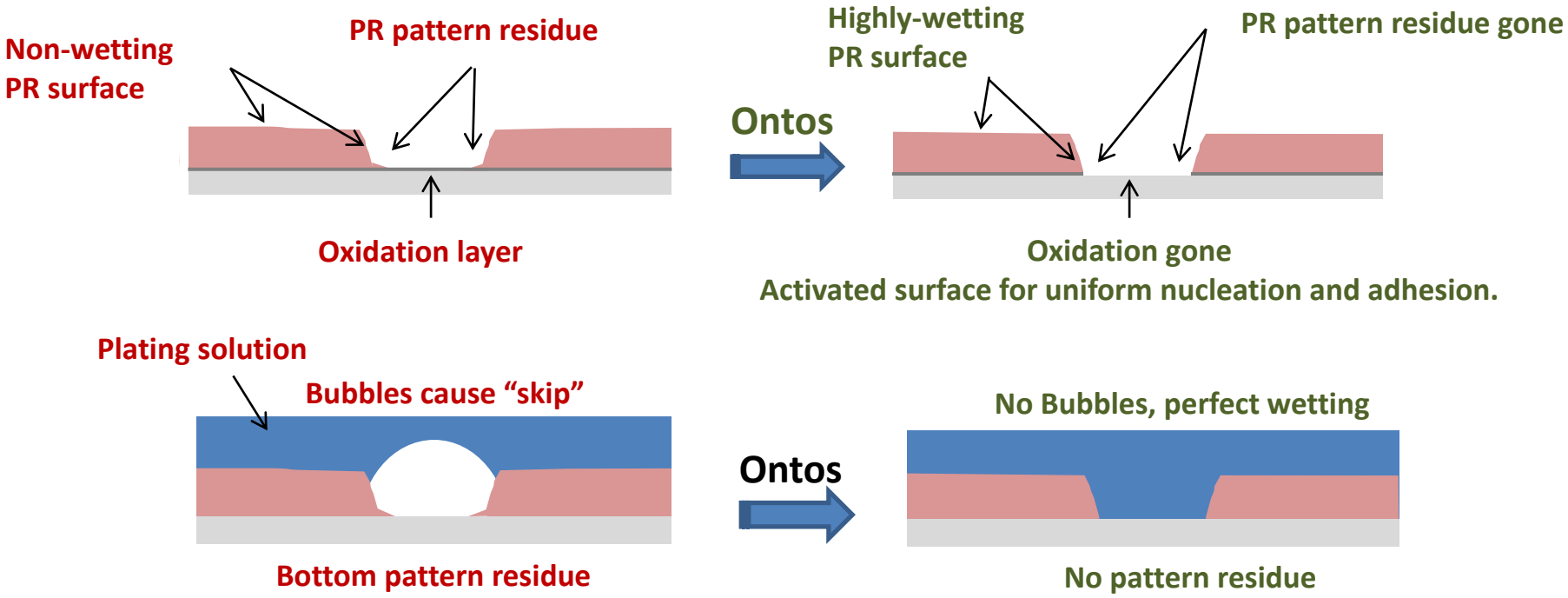
- Ontos removes undesirable oxidation, organic contamination, creates a pristine surface **without surface damage**.
- Controlled passivation of the surface with Oxygen or Nitrogen or ??
  - Mesa sidewalls
  - Exposed junction edges
  - Detector backside surface flatband adjustment, activated controlled surface for backside A-R coat.



7. PREPARATION FOR PLATING

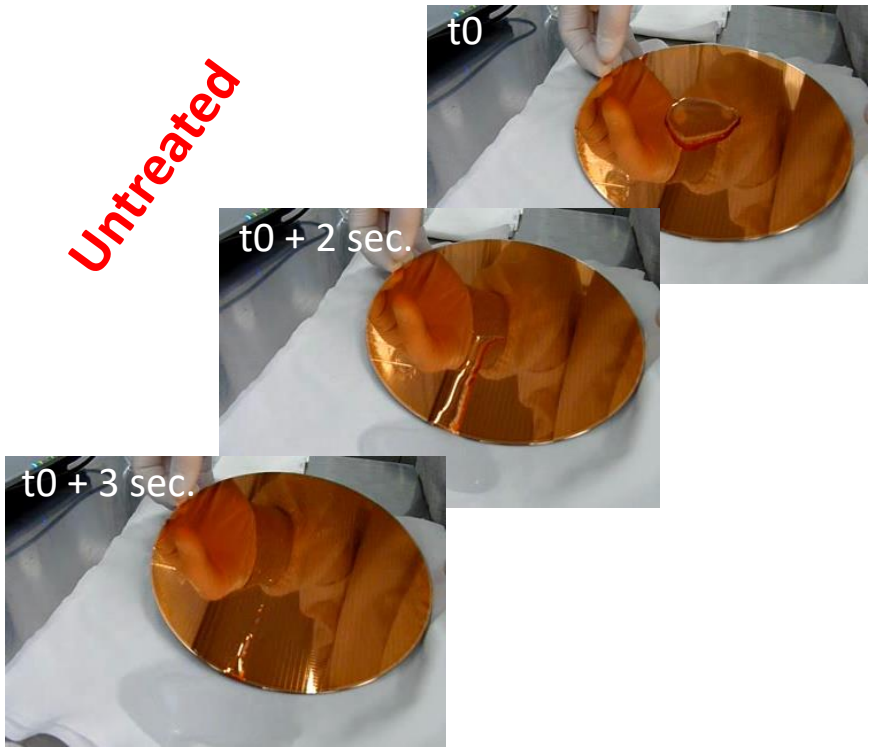
Use Ontos with **reducing** chemistry before plating

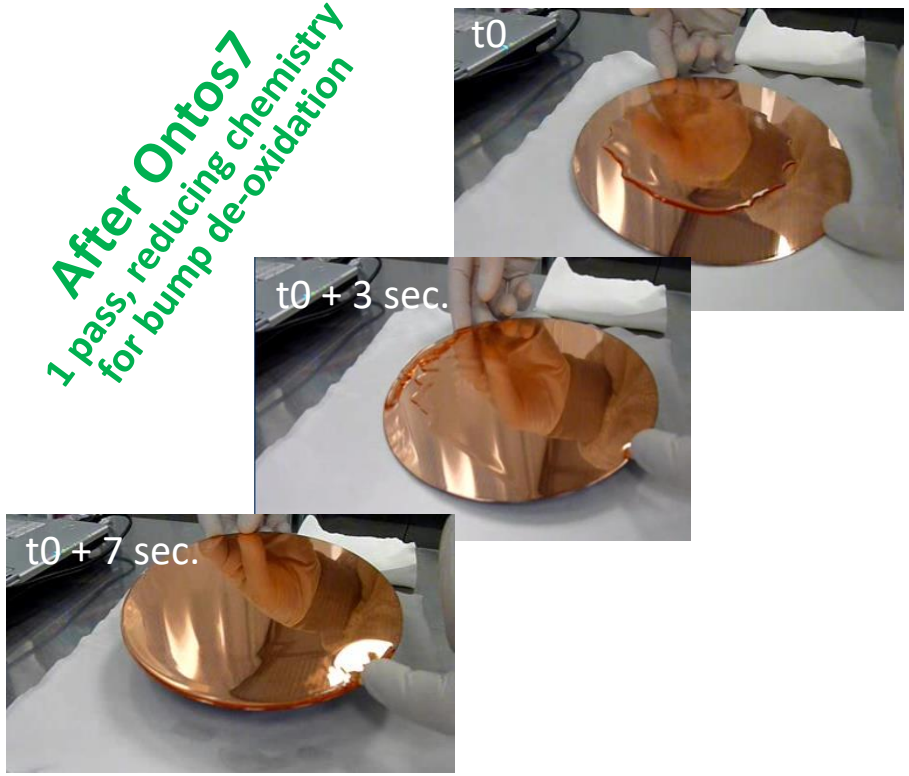
- Descum the PR pattern to remove bottom residue (without Oxygen!).
- De-oxidize the exposed plating base surface for uniform nucleation.
- Activate the plating base surface for maximum adhesion.



7. PHOTORESIST DESCUM AND ACTIVATION

Positive PR over Cu plating base





No wetting of Photoresist or metal pattern

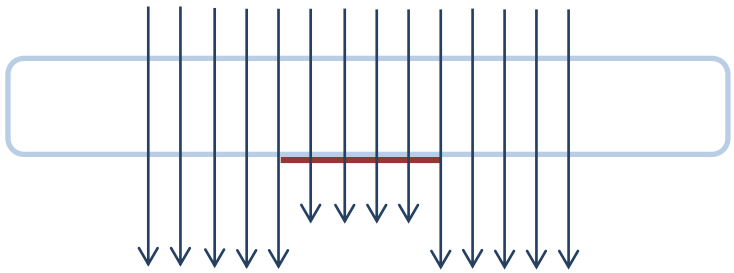
- **Process voids**
- **Non-uniformity**
- **Time control issues**

Superb wetting of both Photoresist and Metal

- **Wets smallest features**
- **Cross-wafer uniformity**
- **Timing consistency**

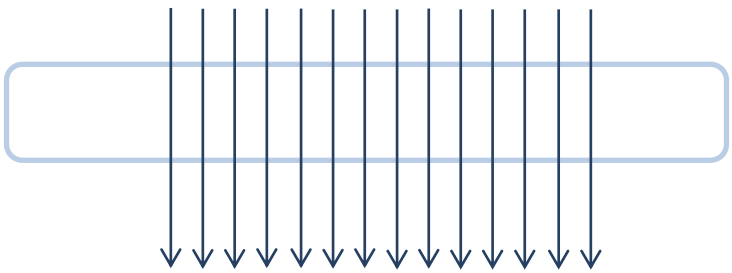
8. PHOTOMASK CLEANING

- Removes organic contamination without damaging sensitive mask materials. (safe for ALL masking materials, even EUVL)
- Enables extreme wetting for aqueous cleaning processes – spot-free.

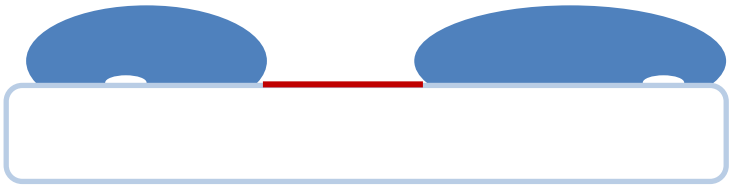


Slightest PR residue inhibits UV transmission causes uneven exposure

Ontos



PR residue removed
Get uniform exposure



Slightest PR residue makes surface impossible to wet, poor wet cleaning results

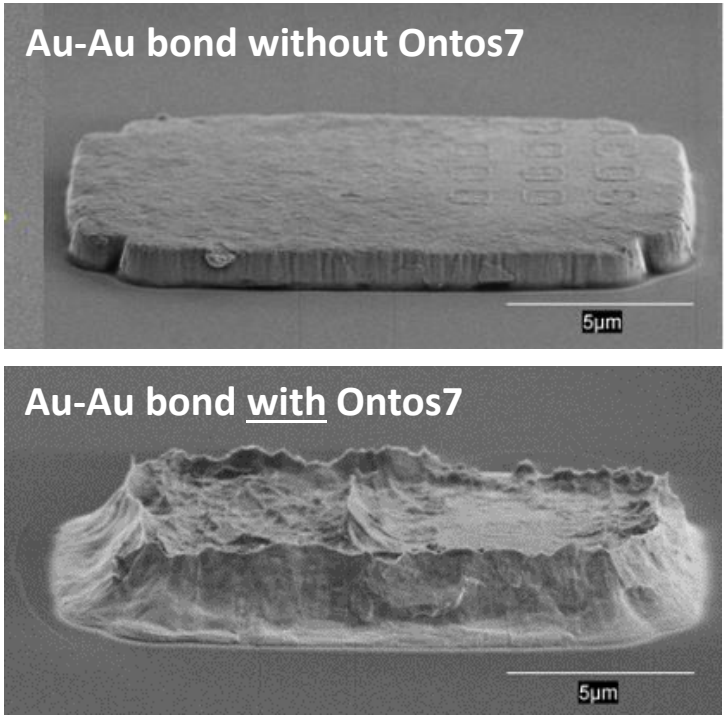
Ontos

PR residue removed
Mask surface activated for uniform wet clean

Ontos produces a pristine, activated surface for:

- **Direct Bonding:**
  - Semiconductor-to-semiconductor (at RT)
  - Oxide-to-Oxide (at RT)
  - Oxide-to-Nitride (at RT)
  - Oxide-to-semiconductor (at RT)
- **Metal-to-metal:**
  - Au – Au (As low as 100°C)
  - In – In (at RT) (see next page)
  - In – metal pad (at RT)
  - In – Ag (at RT)
  - SnAg – Cu (at 175°C)
  - SAC – Cu (at 175°C)
  - SAC – SAC (at 175°C)
  - … more

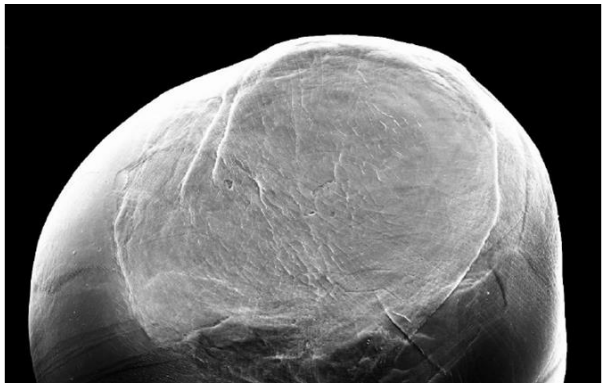
Gold bump after Pull Test (200°C)



9. METAL-TO-METAL BONDING (INDIUM BUMPS)

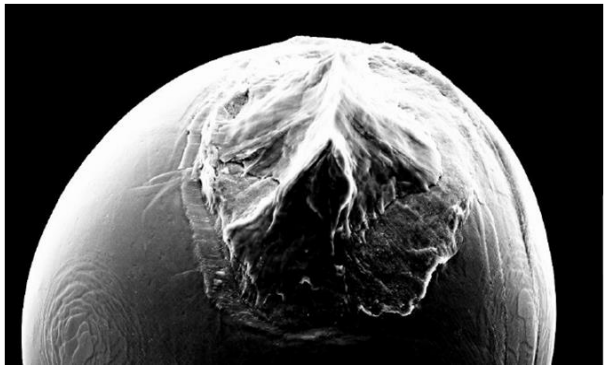
Indium bump to Indium bump (70µ bumps)

- No surface treatment.
- Room temperature compression (1g/bump)
- No post-bond reflow.
- Pull test shows Indium compression but zero adhesion



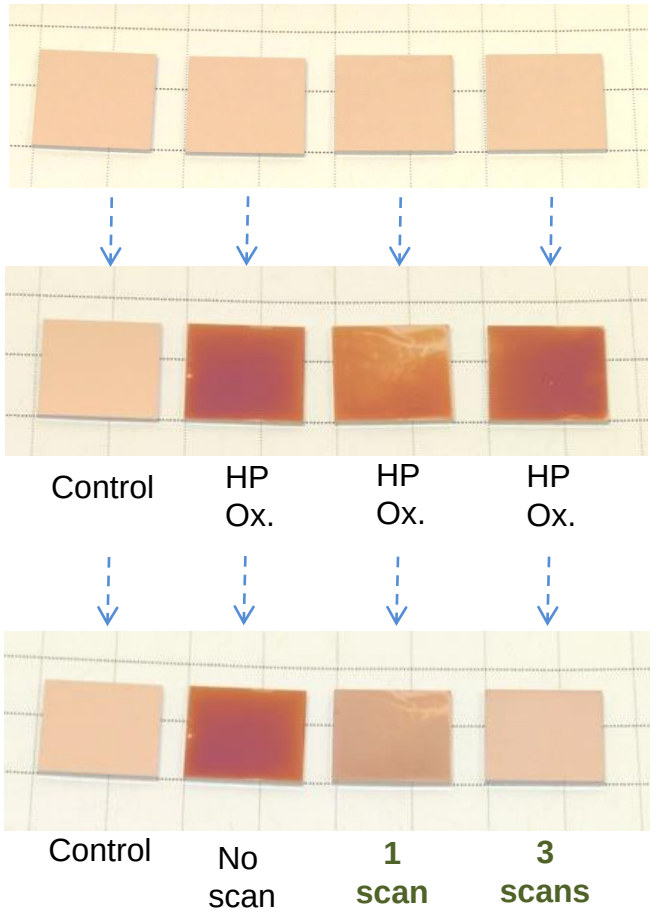
Indium bump to Indium bump (70µ bumps)

- Both surfaces Ontos7-treated.
- Room temperature compression (1g/bump)
- No post-bond reflow.
- Pull test shows ideal tensile rupture of Indium.



9. METAL-TO-METAL BONDING (COPPER 1/2)

Removing Heavy Copper Oxide at Room Temperature



4 Cu/Si coupons out of the box

3 coupons hotplate oxidized – 150°C, 12 minutes (Approximately 400 Angstroms)

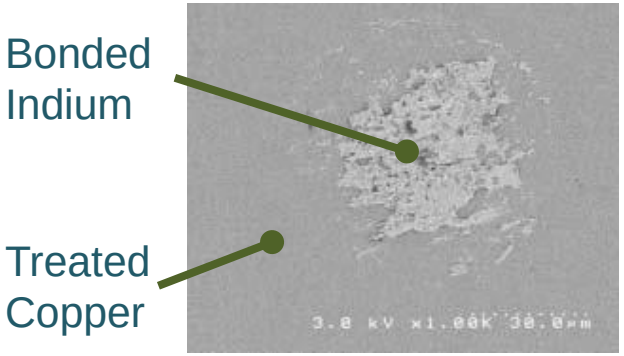
Atmospheric Plasma reduces Cu Oxide at R.T.
3 scans returns Cu to native state.

9. METAL-TO-METAL BONDING (COPPER 2/2)

Bonding to Copper Treated with Ontos

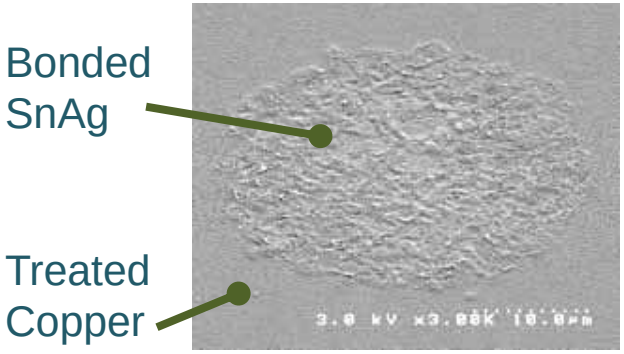
Indium to Copper

- Both surfaces treated.
- Room temperature compression.
- **No reflow**.
- Shear test shows In bonded to Cu.



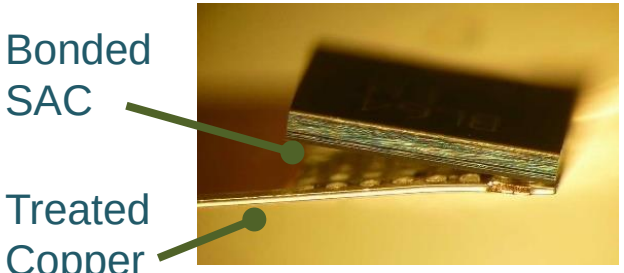
SnAg to Copper

- Both surfaces treated.
- 185°C thermo-compression in air.
- **No reflow**
- Shear test shows SnAg bonded to Cu.



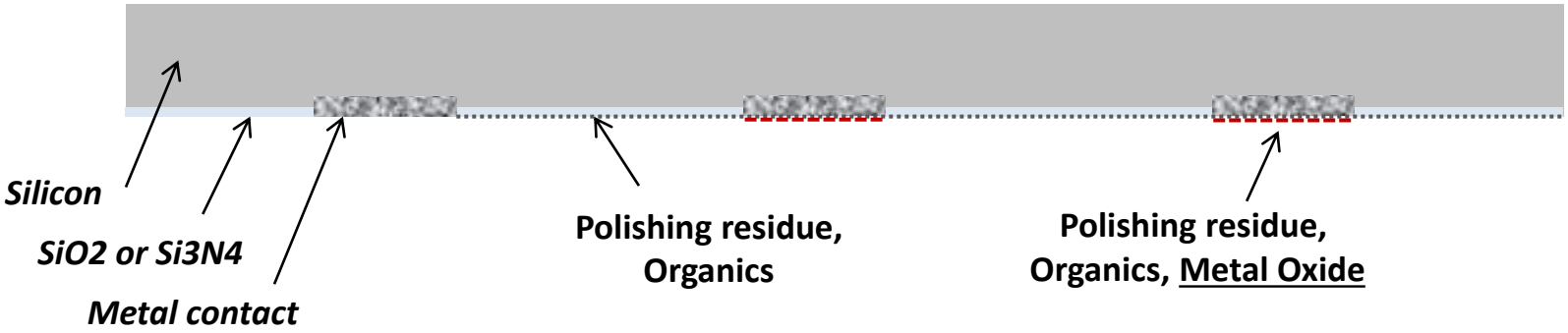
SAC to Copper

- Both surfaces treated.
- 280°C thermo-compression in air.
- Shear test shows SAC bonded to Cu.
- Very strong adhesion, bent Cu substrate.

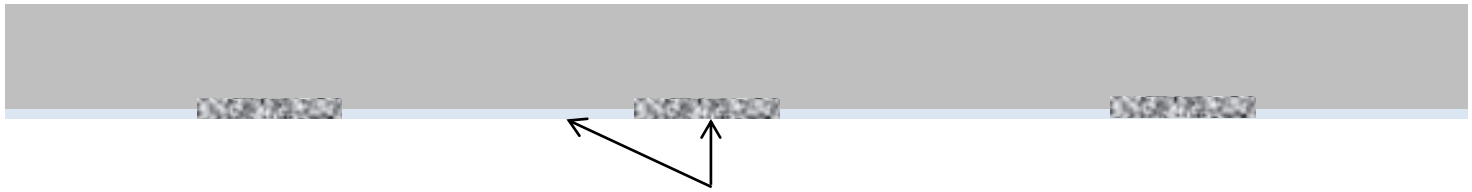


Ontos surface preparation for a W2W or D2W bonding process:

- **Staged Parts - Surface Condition:**



- **After Ontos Prep with reducing + passivating dry chemistry:**



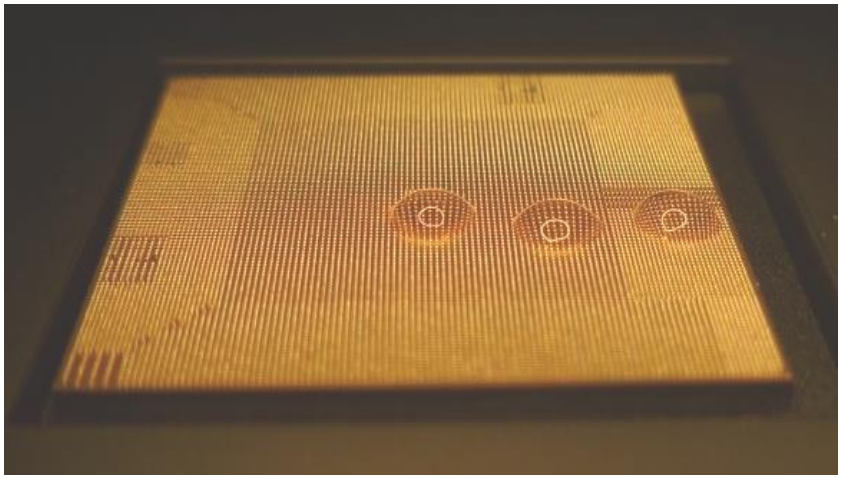
Pristine surfaces

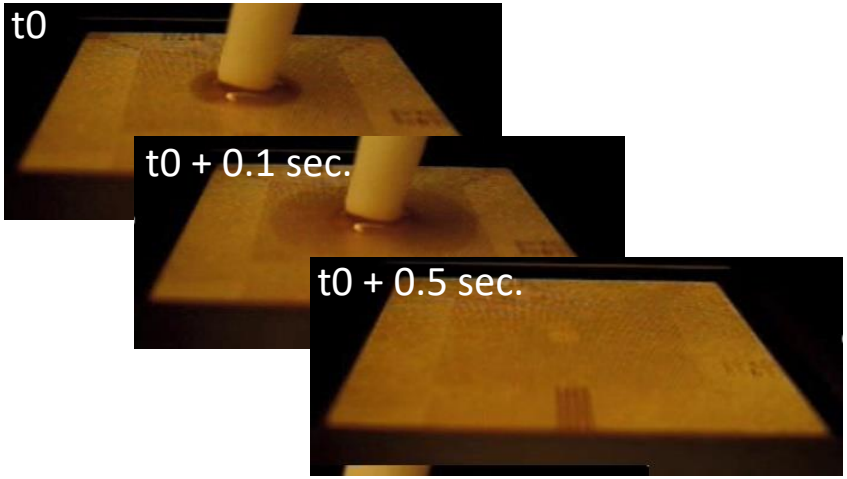
Dielectric and metal cleaned, and passivated with monolayer of Nitrogen

Ideal for direct bond of dielectric and ohmic contacts

10. SURFACE ACTIVATION (CAPILLARY UNDERFILL)

Example: High-density Bumps (SnAg) on BGA chip (Si_3N_4 Passivation)





Untreated:

- No wetting of the bumps or Si_3N_4 passivation
- **Poor wicking and adhesion of underfill**

After treatment with Ontos:

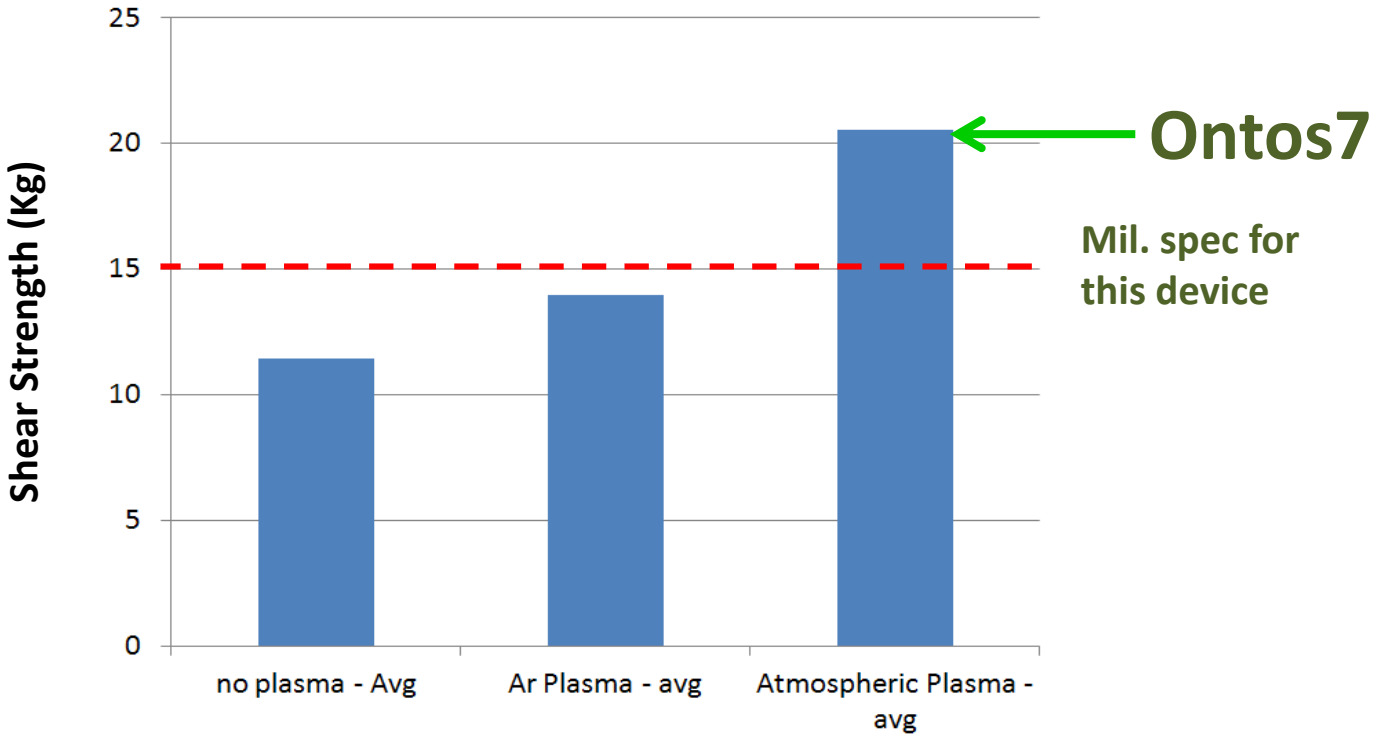
- Using reducing chemistry for bump de-oxidation of chip and substrate before flip chip.

  Superb wetting of both bumps and passivation.
- **Excellent wicking and adhesion of underfill in flip chip gap.**

11. SURFACE ACTIVATION (DIE ATTACH ADHESION)

Ontos7 reducing chemistry creates clean, activated surfaces for adhesive bonding:

Example: Epoxy adhesion of Si chip to Al_2O_3 substrate.



Ontos7 nearly **doubles** the shear strength **over no preparation**; and does **50% better than Argon plasma**.

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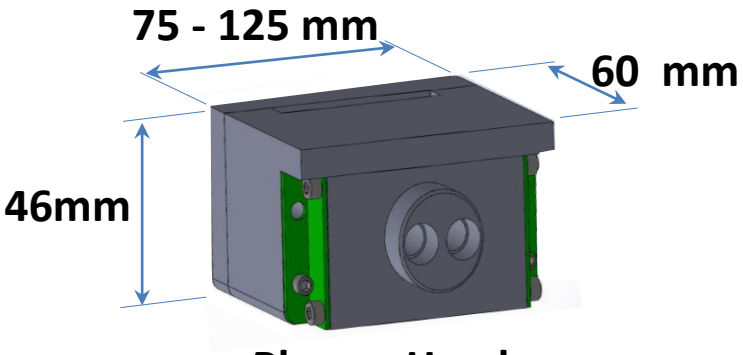
Ontos7

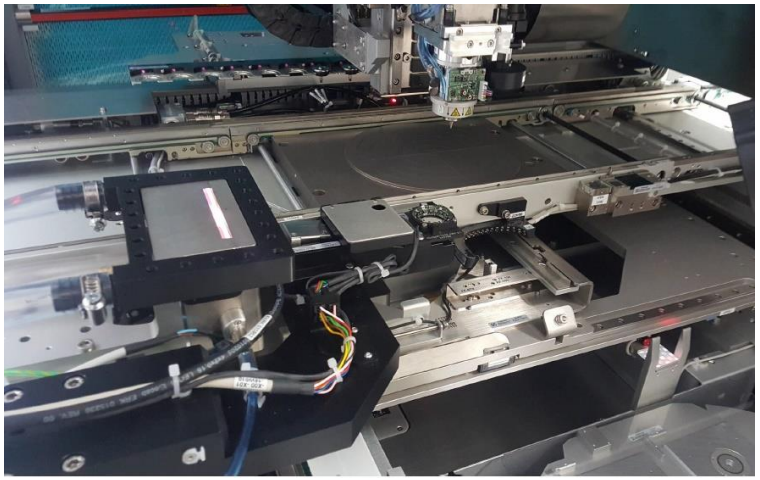
ONTOS OEM SYSTEM INTEGRATION 1/2

- **Up to 85mm (die level processing):**



Plasma Head

Example: BESI 2200 EVO
With integrated Ontos Plasma Head for die activation

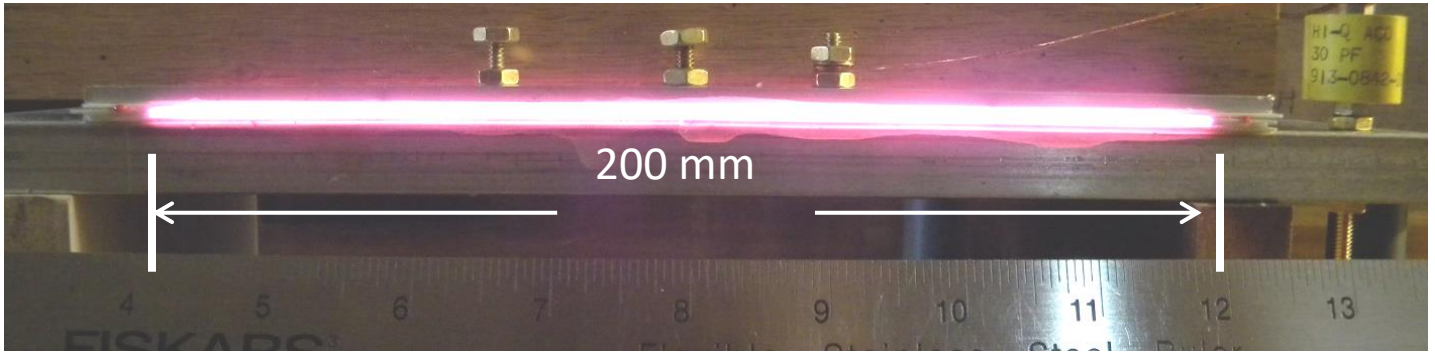


RF Matching Network

RF Power Module

Gas Control Module

WAFER-LEVEL SCALING IN DEVELOPMENT

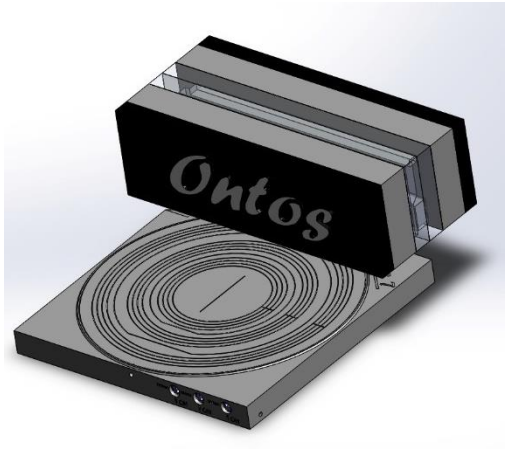


Bench Demonstration 200 mm Ontos Atmospheric Plasma Head
(We anticipate this approach to be scalable to 300 mm)

- Coming soon:
  - 200mm and 300mm OntosPro AP sources.
  - To be available as stand-alone systems for frontend and backend fabs.
  - To be available as OEM components for integration into semiconductor fab equipment

ONTOS OEM SYSTEM INTEGRATION 2/2

- **200-300 mm (future):**



Plasma Head

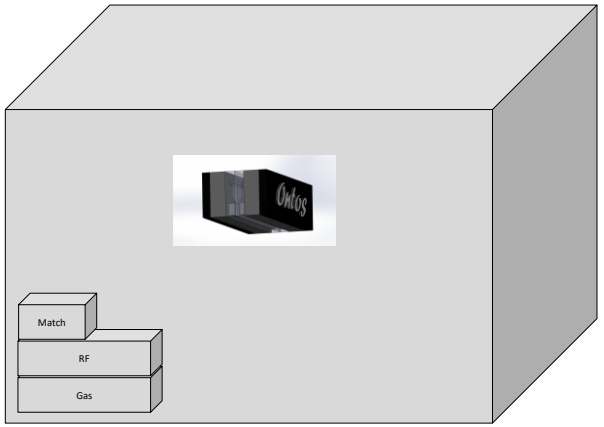
RF Matching Network

RF Power Module

Gas Control Module

Stand-alone SMIF or FOUP

Your System



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CONCLUSIONS

- Ontos Atmospheric Plasma provides rapid effective surface preparation for an important variety of semiconductor materials and processes.
- It addresses oxidation, contamination, wetting, and adhesion issues in nearly all aspects of Semiconductor manufacturing with high throughput, reasonable cost, and zero energetic damage.
- Improve your process yield and performance with Ontos:
  - Up to 200 mm wafer processing with a 25 mm scanning system.
  - 200-300mm wafer scale systems in development.
  - Be an industry leader in the new era of atmospheric plasma wafer and die processing.

CONTACT US FOR A DEMO ON YOUR PARTS

Demo Lab in USA (Ventura-CA)

Demo Lab in Europe (Fraunhofer-IZM, Berlin)
(by special arrangement)

Our Demo Labs are ready to
demonstrate our capabilities on your parts. Call us:

Matt Phillips: 603-548-7870 (NH)
Eric Schulte: 805-637-5723 (CA)
Gilbert Lecarpentier: +33 (0)6 71 84 69 71 (France)

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SETNA INTRODUCTION

- July 2007 – SETNA established to represent SET high-accuracy bonders in North America: sales, applications, and service.
- March 2011 - SETNA establishes Ontos Equipment Systems (OES) to develop and manufacture the Atmospheric Plasma for surface preparation.

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Advantages of Ontos Over Vacuum Plasma (1/2)

- Eliminates the need for expensive vacuum plasma equipment,
- Speeds up process throughput from 30 minutes to around 1-3 minutes per wafer; smaller die in seconds.
- Eliminates the potential for vacuum plasma damage to the components due to direct exposure to hot electrons, ions, and high kinetic energy atoms,
- Eliminates the possibility of back-sputtering of unwanted metals and contaminants from vacuum chamber components onto the substrate being treated,
- Eliminates the possibility of re-deposition of etch products (often as particles) back onto the substrate being treated,
- Capable of continuous-feed processing vs. batch processing in a chamber,
- Eliminates expensive and time-consuming maintenance requirements of vacuum systems,

Advantages of Ontos Over Vacuum Plasma (2/2)

- Additionally, and very significantly, the traditional RIE cleaning method only removes oxidation from the metallic contacts very temporarily, since the oxide re-grows rapidly when exposed to air after the chamber is vented. If subsequent processes cannot be performed in a very short period of time, and/or if the process is performed at elevated temperature, the re-grown oxide inhibits contact to metallic surfaces. Ontos is capable of passivating metal surfaces against re-oxidation for hours.
- Note: Inexpensive (roughing pump only) vacuum plasma ashing systems are not suitable for removing oxides with reducing chemistries, because they cannot pump out enough oxygen from the chamber to allow the reducing chemistry to act on the surface of your chips. In comparison, the Ontos7 Atmospheric Plasma system uses a directed flow of process gas in the reaction zone to ensure zero Oxygen in the reaction zone.

Advantages of Ontos Over Other AP Systems (1/2)

- Most atmospheric plasma systems employ “Corona Discharge” or “Plasma Torch” technology.
  - Corona Discharge AP systems are like a lightning storm next to your wafer. They are well-known to cause severe damage to CMOS and other sensitive devices. Typically used on textiles and plastics to make them receptive to dyes, paints, and adhesives. Sputtered electrode metal will contaminate sensitive semiconductor substrates.
  - Plasma Torch AP systems run at extremely high downstream temperatures – typically 1000’s of degrees C. Good for welding; not so good for atomic layer surface treatment.
- Ontos is a “Dielectric Barrier Glow Discharge” plasma. This is a low-temperature plasma, which is 100% confined within the head, and never comes in contact with the substrate.
  - All of the reactive chemistry is accomplished in the remote downstream radicals from the plasma. No ions, no hot electrons, no bombardment.
  - The Ontos plasma cavity is designed for both reducing chemistry and oxidizing chemistry.

Advantages of Ontos Over Other AP Systems (2/2)

- Our singular competitor in Glow Discharge plasma has designed the interior of their plasma head to be compatible only with Oxygen or inert chemistries. Reducing chemistries (Hydrogen-containing) will quickly consume the internal thin-film dielectrics, and the plasma head will begin to arc. Ontos employs pure quartz dielectric for zero arcing and spalling.
  - This competitor is concentrated in treating polymers for improved adhesion, and has near-zero experience with semiconductor applications. This shows in their designs and results.
  - The competitor's plasma head and match network have very narrow operating range of power, gas flow, gas composition. Ontos is extremely stable over a broad range of operating parameters.
- Ontos was specifically designed for the semiconductor industry by semiconductor experts.
  - 130 years of combined experience in semiconductor processing.

SURFACE PREPARATION TECHNIQUES MATRIX

	Solvent only	UV Ozone or 02 Ash	Wet Etch	Vacuum RIE	Atmospheric Plasma
Removes most organics	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Removes all organics	**No**	**No**	**No**	**Yes**	**Yes**
Removes native sub-oxides	**No**	**No-No!**	**Yes**	**Yes**	**Yes**
Clean Process – no particle generation	**No**	**No**	**No**	**No**	**Yes**
Safe for CMOS, Sensitive Components	**Yes**	**No?**	**Yes?**	**?**	**Yes**
Process completes in seconds	**Yes**	**No**	**No**	**No**	**Yes**
Environmentally friendly chemistry	**???**	**No**	**No**	**Yes**	**Yes**
Surface Passivation against re-oxidation	**No**	**No**	**No**	**No**	**Yes**