# Cold Plasma Technology as an Alternative to Vapor Degreasing

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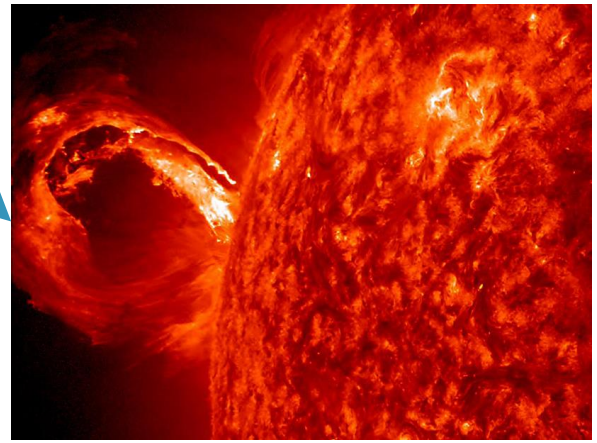
# What exactly is Cold Plasma?

- Plasma is ionized gas, a state of matter made of electrically charged particles.

***This is hot (or thermal) plasma***

High pressure and temperature



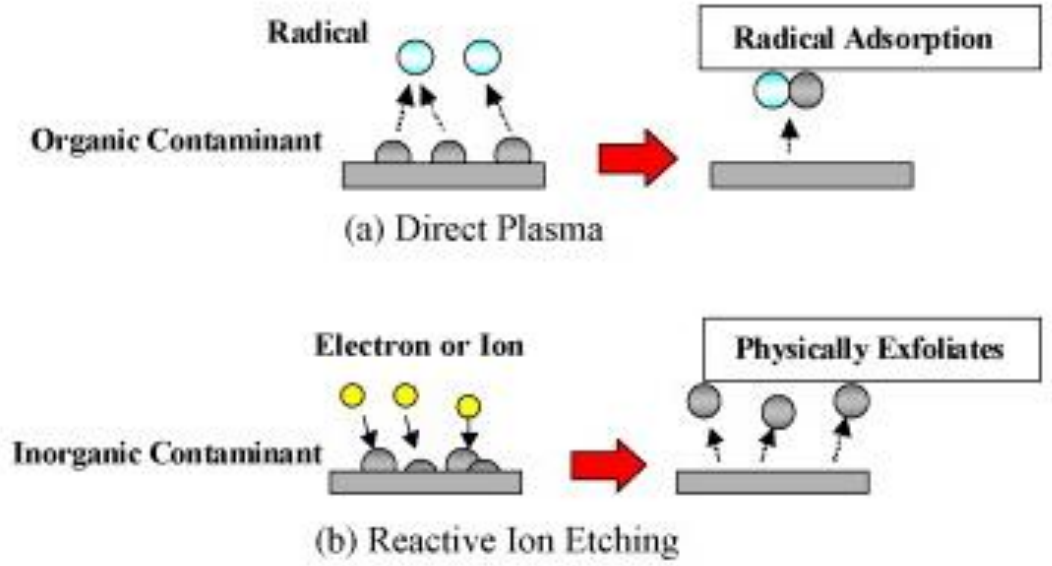

***This is cold (or atmospheric) plasma***

Atmosphere pressure (or vacuum) and moderated temperatures

- Cold plasma is generated by an oscillating electric field (microwaves or radiofrequency) to ionize gas molecules.
- Some applications for (low intensity) cold plasma:
  - ***Surface cleaning:*** removes oil, grease, and bacteria.
  - ***Plasma etching:*** coating metals with a controlled layer of oxide.
  - ***Plasma deposition:*** deposit materials onto metallic, plastic or ceramic surfaces.
  - ***Biomedicine:*** R&D for use in wound healing, beauty and cancer treatment.

# Cold plasma mode of action

- The charged particles present in the plasma adsorb and react with any loose soil.
- Low intensity cold plasma can clean surfaces in atmospheric conditions at low temperatures without requiring solvent use*.
- Since atmospheric plasma operates at near-ambient temperatures, it can be applied to heat-sensitive materials.
- Moreover, the technology is readily available on the market for the electronic, metalworking, and plating industries.




* Nakamura et al. (2009) https://doi.org/10.1016/j.apsusc.2009.05.121

# Two modes of operation: Direct and indirect

Plasma Chamber


**Small parts.**
**Batch operation.**
**Easy VOC emission control.**
**Vacuum + Plasma -> Cleaning**

The **direct** mode of operation is achieved by placing the substrate between the electrodes, usually in reduced-pressure chambers.

**Indirect** plasma (also called *post-discharge*) is propelled through a tip where the plasma contacts the substrate surface in the form of a jet.

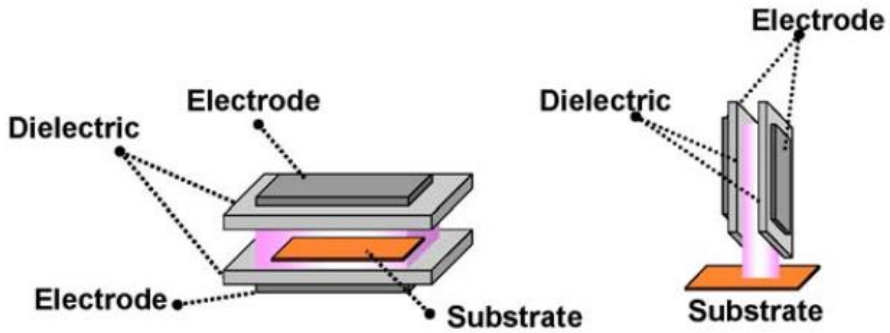
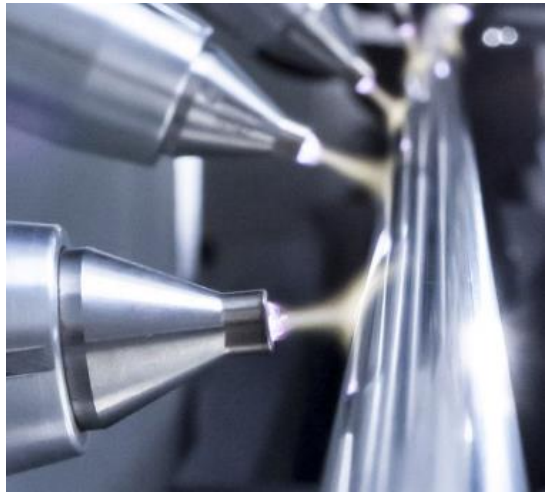



**Fig. 4.** Reactor form. (a) Direct type and (b) indirect type.

Plasma Jet



**Large parts.**
**Batch or continuous mode.**
**Automated setting.**
**Jet impact + Plasma -> cleaning**

* Nakamura et al. (2009) https://doi.org/10.1016/j.apsusc.2009.05.121

Monitoring pressure and gas flow rate is key for process repeatability and consistency.

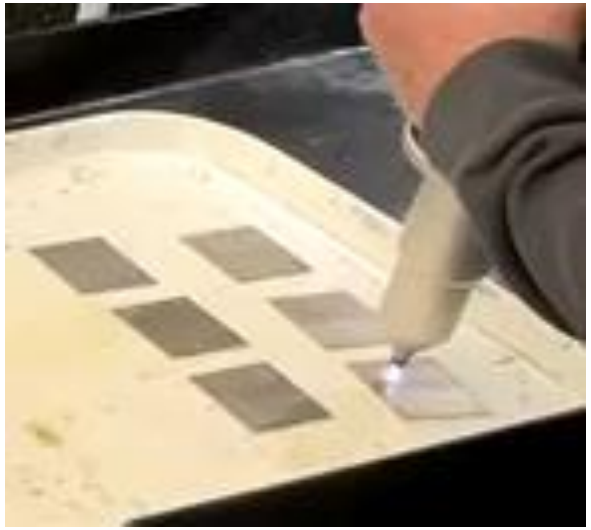
# Plasma Jet in action

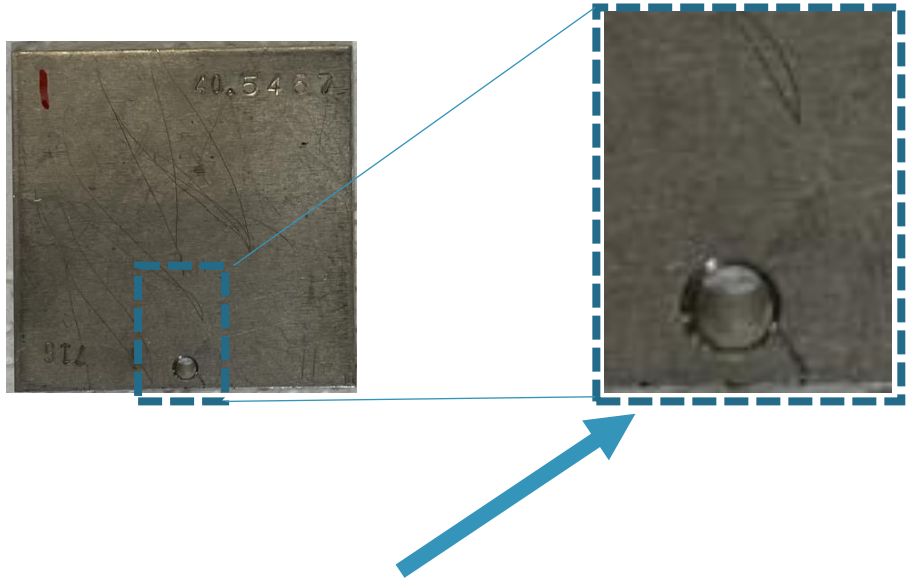
Images and videos from Plasmatreat visit to TURI (Dec. 2022)

**Contaminate:** Cutting Oil

**Substrate:** Nickel Plated Copper

**Cleaning agent:** Plasmatreat Rotating Jet RD1004HVC; standard jet nozzle; 10 mm depth





Treated sample: Wettability as new (visual drop test), 95%+ oil removal in seconds

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# Plasma Jet in action

Images and videos from Plasmatreat visit to TURI (Dec. 2022)

**Contaminate:** Paint

**Substrate:** Stainless steel cutting tool part

**Cleaning agent:** Plasmatreat Rotating Jet RD1004HVC; standard jet nozzle; 5 mm depth

**Removal time:** 2-3 seconds on the spot, quick and easy (vs. immersion and scrubbing with TCE).

***Optimization variables:***

- Residence time over cleaning spot.
- Nozzle – surface distance.
- Carrier gas (air, oxygen, …)

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# Cold Plasma Technology as an alternative to vapor degreasing for parts cleaning.

| Open top | Classic enclosed | Airless enclosed |
|---|---|---|
| Cheapest option (150 – 300 USD) | Moderate CapEx (10K – 40K USD) | High CapEx (300K – 500K USD) |
| Highest solvent exposure | Some control of solvent exposure | Lowest solvent exposure |
| Low solvent use efficiency | Moderate solvent use efficiency | Solvent recycling capacity (one charge lasts years) |
| No fire protection | Weak fire protection | Can use flammable solvents (in proper building) |


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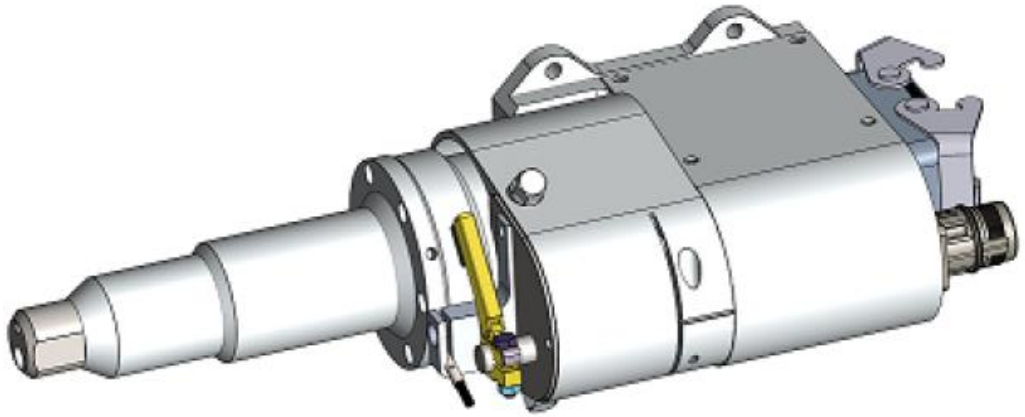
# Cold Plasma Technology as an alternative to vapor degreasing for parts cleaning.

| Plasma Chamber | Plasma Jet |
|---|---|
| Low CapEx (10K USD / unit)<br>***No solvent use***<br>Ideal for small parts<br>Batch mode | Moderated CapEx (about 70K USD / unit)<br>***No solvent use***<br>Ideal for big parts in automated setting<br>Continuous production, high throughput |

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# Comparative SWOT analysis

| Technology | Classic vapor degreasing | Airless vapor degreasing | Plasma chamber | Plasma Jet |
|---|---|---|---|---|
| **Strength** | • Low CapEx.<br>• Known technology. | • High solvent use efficiency.<br>• Solvent recycling.<br>• Elimination of workers' exposure to solvent. | • Solventless alternative.<br>• Ideal for small parts.<br>• Easy VOC emission control. | • Solventless alternative.<br>• Faster paint removal than solvents. |
| **Weakness** | • Works with non-flammable, mostly halogenated, solvents.<br>• TURA, HazMat and disposal fees. | • Exceedingly high investment.<br>• Very low ROI. | • Not scalable to medium to large surfaces.<br>• Batch processing.<br>• Hard to reach complex shape features (blind holes, grooves, etc.). | • Additional investment in routing or robotic arms for its operation.<br>• Complex parts can be tricky. |
| **Opportunities** | • Improving solvent use efficiency.<br>• Safer solvents may (or may not) be available. | • TURA fee savings<br>• Eliminating TCE use could attract external funding. | • TURA fee savings<br>• Hazmat fee savings.<br>• Low investment.<br>• Large ROI. | • TURA fee savings.<br>• HazMat fee savings.<br>• Moderate investment.<br>• Large ROI. |
| **Threats** | • Halogenated solvents are toxic to workers and the environment. | • Greener solvent alternatives are flammable. | • Several units might be required.<br>• Requires VOC filtering. | • Several units might be required.<br>• Requires VOC control. |

# Work in the near future

- Development of a systematic methodology to evaluate the cleaning efficacy of cold plasma on industrially relevant surfaces stained with various soils.
- Compare cleaning performances between plasma jet and plasma chamber.
- Compare the degreasing performance with halogenated solvents: perchloroethylene (PCE), trans-dichloroethylene (tDCE), n-propyl bromide (nPB), etc.
- Feasibility analysis of cold plasma technology in diverse scenarios.
- Assess the feasibility of plasma activated water for disinfection.


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